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**Gurin**

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(54) **HEAT PUMP WITH INTEGRAL SOLAR COLLECTOR**

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See application file for complete search history.

(56) **References Cited**

#### **U.S. PATENT DOCUMENTS**

2,575,478	A	11/1951	Wilson
2,634,375	A	4/1953	Guimbal
2,691,280	A	10/1954	Albert
3,095,274	A	6/1963	Crawford

(Continued)

#### **FOREIGN PATENT DOCUMENTS**

CA	2794150	A1	11/2011
CN	1165238	A	11/1997

(Continued)

#### **OTHER PUBLICATIONS**

CN Search Report for Application No. 201080035382.1, 2 pages.

(Continued)

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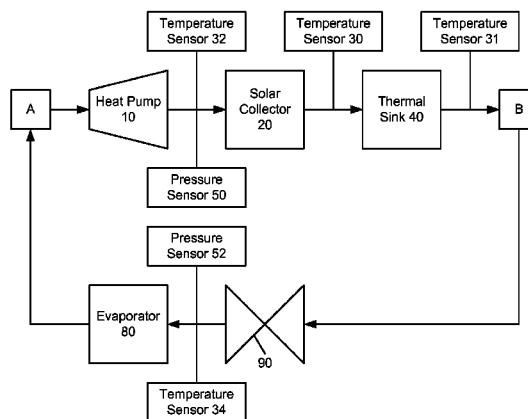
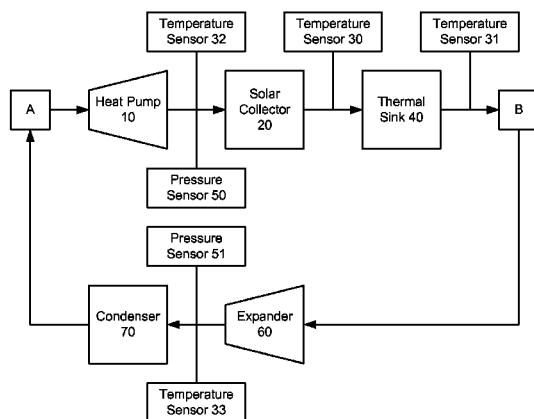
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(57)

#### **ABSTRACT**

The present invention generally relates to heat pumps that utilize at least one solar receiver operating with the same working fluids. In one embodiment, the present invention relates to a hybrid solar heat pump comprised of at least one microchannel heat exchanger with integral solar absorber, at least one compression device as the heat pump for concurrent compression to a higher pressure and mass flow regulator of the working fluid, and at least one working fluid accumulator with the entire system operating with the same working fluid.

**6 Claims, 12 Drawing Sheets**



(56)

## References Cited

## U.S. PATENT DOCUMENTS

3,105,748	A	10/1963	Stahl	4,773,212	A	9/1988	Griffin	
3,237,403	A	3/1966	Fehér	4,798,056	A	1/1989	Franklin	
3,277,955	A	10/1966	Heller	4,813,242	A	3/1989	Wicks	
3,401,277	A	9/1968	Larson	4,821,514	A	4/1989	Schmidt	
3,622,767	A	11/1971	Koepcke	4,867,633	A	9/1989	Gravelle	
3,630,022	A	12/1971	Jubb	4,892,459	A	1/1990	Guelich	
3,736,745	A	6/1973	Karig	4,986,071	A	1/1991	Voss	
3,772,879	A	11/1973	Engdahl	4,993,483	A	2/1991	Harris	
3,791,137	A	2/1974	Jubb	5,000,003	A	3/1991	Wicks	
3,830,062	A	8/1974	Morgan et al.	5,050,375	A	9/1991	Dickinson	
3,939,328	A	2/1976	Davis	5,080,047	A *	1/1992	Williams et al.	122/35
3,971,211	A	7/1976	Wethe	5,083,425	A	1/1992	Hendriks et al.	
3,982,379	A	9/1976	Gilli	5,098,194	A	3/1992	Kuo	
3,998,058	A	12/1976	Park	5,102,295	A	4/1992	Pope	
4,009,575	A	3/1977	Hartman, Jr.	5,104,284	A	4/1992	Hustak, Jr.	
4,015,962	A *	4/1977	Tompkins	5,164,020	A	11/1992	Wagner	
4,029,255	A	6/1977	Heiser	5,176,321	A	1/1993	Doherty	
4,030,312	A	6/1977	Wallin	5,203,159	A	4/1993	Koizumi	
4,049,407	A	9/1977	Bottum	5,228,310	A	7/1993	Vandenberg	
4,070,870	A *	1/1978	Bahel et al.	5,291,960	A	3/1994	Brandenburg	
4,099,381	A	7/1978	Rappoport	5,320,482	A	6/1994	Palmer et al.	
4,119,140	A	10/1978	Cates	5,335,510	A	8/1994	Rockenfeller	
4,150,547	A	4/1979	Hobson	5,358,378	A	10/1994	Holscher	
4,152,901	A	5/1979	Munters	5,360,057	A	11/1994	Rockenfeller	
4,164,848	A	8/1979	Gilli	5,392,606	A	2/1995	Labinov	
4,164,849	A	8/1979	Mangus	5,440,882	A	8/1995	Kalina	
4,170,435	A	10/1979	Swearingen	5,444,972	A	8/1995	Moore	
4,182,960	A	1/1980	Reuyl	5,488,828	A	2/1996	Brossard	
4,183,220	A	1/1980	Shaw	5,490,386	A	2/1996	Keller	
4,198,827	A	4/1980	Terry et al.	5,503,222	A	4/1996	Dunne	
4,208,882	A	6/1980	Lopes	5,531,073	A	7/1996	Bronicki	
4,221,185	A	9/1980	Scholes	5,538,564	A	7/1996	Kaschmitter	
4,233,085	A	11/1980	Roderick	5,542,203	A	8/1996	Luoma	
4,236,869	A	12/1980	Laurello	5,570,578	A	11/1996	Saujet	
4,245,476	A *	1/1981	Shaw	5,588,298	A	12/1996	Kalina	
4,248,049	A *	2/1981	Briley	5,600,967	A	2/1997	Meckler	
4,257,232	A	3/1981	Bell	5,634,340	A	6/1997	Grennan	
4,287,430	A	9/1981	Guido	5,647,221	A	7/1997	Garris, Jr.	
4,336,692	A	6/1982	Ecker	5,649,426	A	7/1997	Kalina	
4,347,711	A	9/1982	Noe	5,676,382	A	10/1997	Dahlheimer	
4,347,714	A	9/1982	Kinsell	5,680,753	A	10/1997	Hollinger	
4,372,125	A	2/1983	Dickenson	5,738,164	A	4/1998	Hildebrand	
4,384,568	A	5/1983	Palmatier	5,754,613	A	5/1998	Hashiguchi	
4,391,101	A	7/1983	Labbe	5,771,700	A	6/1998	Cochran	
4,420,947	A	12/1983	Yoshino	5,789,822	A	8/1998	Calistrat	
4,428,190	A	1/1984	Bronicki	5,813,215	A	9/1998	Weisser	
4,433,554	A	2/1984	Rojey	5,833,876	A	11/1998	Schnur	
4,439,687	A	3/1984	Wood	5,862,666	A	1/1999	Liu	
4,439,994	A	4/1984	Briley	5,873,260	A	2/1999	Linhardt	
4,448,033	A	5/1984	Briccetti	5,874,039	A	2/1999	Edelson	
4,450,363	A	5/1984	Russell	5,894,836	A	4/1999	Wu	
4,455,836	A	6/1984	Binstock	5,899,067	A	5/1999	Hageman	
4,467,609	A	8/1984	Loomis	5,903,060	A	5/1999	Norton	
4,467,621	A	8/1984	O'Brien	5,918,460	A	7/1999	Connell	
4,471,622	A *	9/1984	Kuwahara	5,941,238	A	8/1999	Tracy	
4,475,353	A	10/1984	Lazare	5,943,869	A	8/1999	Cheng	
4,489,562	A	12/1984	Snyder	5,946,931	A	9/1999	Lomax	
4,489,563	A	12/1984	Kalina	5,973,050	A	10/1999	Johnson	
4,498,289	A	2/1985	Osgerby	6,037,683	A	3/2000	Lulay	
4,516,403	A	5/1985	Tanaka	6,041,604	A	3/2000	Nicodemus	
4,538,960	A	9/1985	Iino et al.	6,058,930	A	5/2000	Shingleton	
4,549,401	A	10/1985	Spliethoff	6,062,815	A	5/2000	Holt	
4,555,905	A	12/1985	Endou	6,065,280	A	5/2000	Ranasinghe	
4,558,228	A	12/1985	Larjola	6,066,797	A	5/2000	Toyomura	
4,573,321	A	3/1986	Knaebel	6,070,405	A	6/2000	Jerye	
4,578,953	A	4/1986	Krieger	6,082,110	A	7/2000	Rosenblatt	
4,589,255	A	5/1986	Martens	6,105,368	A	8/2000	Hansen	
4,636,578	A	1/1987	Feinberg	6,112,547	A	9/2000	Spauschus	
4,674,297	A	6/1987	Vobach	6,129,507	A	10/2000	Ganelin	
4,694,189	A	9/1987	Haraguchi	6,158,237	A	12/2000	Riffat	
4,697,981	A	10/1987	Brown et al.	6,164,655	A	12/2000	Bothien	
4,700,543	A	10/1987	Krieger	6,202,782	B1	3/2001	Hatanaka	
4,730,977	A	3/1988	Haaser	6,223,846	B1	5/2001	Schechter	
4,756,162	A	7/1988	Dayan	6,233,938	B1	5/2001	Nicodemus	
4,765,143	A	8/1988	Crawford	6,233,955	B1 *	5/2001	Egara	62/196.4
				6,282,900	B1	9/2001	Bell	
				6,282,917	B1	9/2001	Mongan	
				6,295,818	B1	10/2001	Ansley	
				6,299,690	B1	10/2001	Mongeon	

(56)

## References Cited

## U.S. PATENT DOCUMENTS

6,341,781	B1	1/2002	Matz	7,600,394	B2	10/2009	Kalina
6,374,630	B1	4/2002	Jones	7,621,133	B2	11/2009	Tomlinson
6,393,851	B1	5/2002	Wightman	7,654,354	B1	2/2010	Otterstrom
6,432,320	B1	8/2002	Bonsignore	7,665,291	B2	2/2010	Anand
6,434,955	B1	8/2002	Ng	7,665,304	B2	2/2010	Sundel
6,442,951	B1	9/2002	Maeda	7,685,821	B2	3/2010	Kalina
6,446,425	B1	9/2002	Lawlor	7,730,713	B2	6/2010	Nakano
6,446,465	B1	9/2002	Dubar	7,735,335	B2	6/2010	Uno
6,463,730	B1	10/2002	Keller	7,770,376	B1	8/2010	Brostmeyer
6,484,490	B1	11/2002	Olsen	7,775,758	B2	8/2010	Legare
6,539,720	B2	4/2003	Rouse et al.	7,827,791	B2	11/2010	Pierson
6,539,728	B2	4/2003	Korin	7,838,470	B2	11/2010	Shaw
6,571,548	B1	6/2003	Bronicki	7,841,179	B2	11/2010	Kalina
6,581,384	B1	6/2003	Benson	7,841,306	B2	11/2010	Myers
6,598,397	B2	7/2003	Hanna	7,854,587	B2	12/2010	Ito
6,644,062	B1	11/2003	Hays	7,866,157	B2	1/2011	Ernst
6,657,849	B1	12/2003	Andresakis	7,900,450	B2	3/2011	Gurin
6,668,554	B1	12/2003	Brown	7,950,230	B2	5/2011	Nishikawa
6,684,625	B2	2/2004	Kline	7,950,243	B2	5/2011	Gurin
6,695,974	B2	2/2004	Withers	7,972,529	B2	7/2011	Machado
6,715,294	B2	4/2004	Anderson	7,997,076	B2	8/2011	Ernst
6,734,585	B2	5/2004	Tornquist	8,096,128	B2	1/2012	Held et al.
6,735,948	B1	5/2004	Kalina	8,099,198	B2	1/2012	Gurin
6,739,142	B2	5/2004	Korin	8,146,360	B2	4/2012	Myers
6,751,959	B1	6/2004	McClanahan	8,281,593	B2	10/2012	Held
6,769,256	B1	8/2004	Kalina	8,419,936	B2	4/2013	Berger et al.
6,799,892	B2	10/2004	Leuthold	2001/0015061	A1	8/2001	Viteri et al.
6,808,179	B1	10/2004	Bhattacharyya	2001/0020444	A1	9/2001	Johnston
6,810,335	B2	10/2004	Lysaght	2001/0030404	A1	10/2001	Liu
6,817,185	B2	11/2004	Coney	2001/0030952	A1	10/2001	Roy
6,857,268	B2	2/2005	Stinger	2002/0029558	A1	3/2002	Tamaro
6,910,334	B2	6/2005	Kalina	2002/0066270	A1	6/2002	Rouse et al.
6,918,254	B2	7/2005	Baker	2002/0078696	A1	6/2002	Korin
6,921,518	B2	7/2005	Johnston	2002/0078697	A1	6/2002	Lifson
6,941,757	B2	9/2005	Kalina	2002/0082747	A1	6/2002	Kramer
6,960,839	B2	11/2005	Zimron	2003/0000213	A1	1/2003	Christensen
6,960,840	B2	11/2005	Willis	2003/0061823	A1	4/2003	Alden
6,962,054	B1	11/2005	Linney	2003/0154718	A1	8/2003	Nayar
6,964,168	B1	11/2005	Pierson	2003/0182946	A1	10/2003	Sami
6,968,690	B2	11/2005	Kalina	2003/0213246	A1	11/2003	Coll et al.
6,986,251	B2	1/2006	Radcliff	2003/0221438	A1	12/2003	Rane et al.
7,013,205	B1	3/2006	Hafner	2004/0011038	A1	1/2004	Stinger
7,021,060	B1	4/2006	Kalina	2004/0011039	A1	1/2004	Stinger et al.
7,022,294	B2	4/2006	Johnston	2004/0020185	A1	2/2004	Brouillette et al.
7,033,533	B2	4/2006	Lewis-Aburn	2004/0020206	A1	2/2004	Sullivan et al.
7,033,553	B2	4/2006	Johnston et al.	2004/0021182	A1	2/2004	Green et al.
7,036,315	B2	5/2006	Kang	2004/0035117	A1	2/2004	Rosen
7,041,272	B2	5/2006	Keefer	2004/0083731	A1	5/2004	Lasker
7,047,744	B1	5/2006	Robertson	2004/0083732	A1	5/2004	Hanna et al.
7,048,782	B1	5/2006	Couch	2004/0088992	A1	5/2004	Brasz et al.
7,062,913	B2	6/2006	Christensen	2004/0097388	A1	5/2004	Brask et al.
7,096,665	B2	8/2006	Stinger	2004/0105980	A1	6/2004	Sudarshan et al.
7,096,679	B2	8/2006	Manole	2004/0107700	A1	6/2004	McClanahan et al.
7,124,587	B1	10/2006	Linney	2004/0159110	A1*	8/2004	Janssen ..... 62/77
7,174,715	B2	2/2007	Armitage	2004/0211182	A1	10/2004	Gould
7,194,863	B2	3/2007	Ganev	2005/0022963	A1	2/2005	Garrabrant et al.
7,197,876	B1	4/2007	Kalina	2005/0056001	A1	3/2005	Frutschi
7,200,996	B2	4/2007	Cogswell	2005/0096676	A1	5/2005	Gifford, III et al.
7,234,314	B1	6/2007	Wiggs	2005/0109387	A1	5/2005	Marshall
7,249,588	B2	7/2007	Russell	2005/0137777	A1	6/2005	Kolavennu et al.
7,278,267	B2	10/2007	Yamada	2005/0162018	A1	7/2005	Realmuto et al.
7,279,800	B2	10/2007	Bassett	2005/0167169	A1	8/2005	Gering et al.
7,287,381	B1	10/2007	Pierson	2005/0183421	A1	8/2005	Vaynberg et al.
7,305,829	B2	12/2007	Mirolli	2005/0196676	A1	9/2005	Singh et al.
7,313,926	B2	1/2008	Gurin	2005/0198959	A1	9/2005	Schubert
7,340,894	B2	3/2008	Miyahara et al.	2005/0227187	A1	10/2005	Schilling
7,340,897	B2	3/2008	Zimron	2005/0252235	A1	11/2005	Critoph et al.
7,406,830	B2	8/2008	Valentian	2005/0257812	A1	11/2005	Wright et al.
7,416,137	B2	8/2008	Hagen et al.	2006/0010868	A1	1/2006	Smith
7,453,242	B2	11/2008	Ichinose	2006/0060333	A1	3/2006	Chordia et al.
7,458,217	B2	12/2008	Kalina	2006/0066113	A1	3/2006	Ebrahim et al.
7,458,218	B2	12/2008	Kalina	2006/0080960	A1	4/2006	Rajendran et al.
7,464,551	B2	12/2008	Althaus et al.	2006/0112693	A1	6/2006	Sundel
7,469,542	B2	12/2008	Kalina	2006/0112702	A1*	6/2006	Martin et al. .... 62/180
7,516,619	B2	4/2009	Pelletier	2006/0182680	A1	8/2006	Keefer et al.
				2006/0211871	A1	9/2006	Dai et al.
				2006/0213218	A1	9/2006	Uno et al.
				2006/0225421	A1	10/2006	Yamanaka et al.
				2006/0225459	A1	10/2006	Meyer

(56)

## References Cited

## U.S. PATENT DOCUMENTS

2006/0249020	A1	11/2006	Tonkovich et al.	2012/0047892	A1	3/2012	Held et al.
2006/0254281	A1	11/2006	Badeer et al.	2012/0067055	A1	3/2012	Held
2007/0001766	A1	1/2007	Ripley et al.	2012/0128463	A1	5/2012	Held
2007/0017192	A1	1/2007	Bednarek et al.	2012/0131918	A1	5/2012	Held
2007/0019708	A1	1/2007	Shiflett et al.	2012/0131919	A1	5/2012	Held
2007/0027038	A1	2/2007	Kamimura et al.	2012/0131920	A1	5/2012	Held
2007/0056290	A1	3/2007	Dahm	2012/0131921	A1	5/2012	Held
2007/0089449	A1*	4/2007	Gurin ..... 62/324.2	2012/0159922	A1	6/2012	Gurin
2007/0108200	A1	5/2007	McKinzie, II	2012/0159956	A1	6/2012	Gurin
2007/0119175	A1	5/2007	Ruggieri et al.	2012/0174558	A1	7/2012	Gurin
2007/0130952	A1	6/2007	Copen	2012/0186219	A1	7/2012	Gurin
2007/0151244	A1	7/2007	Gurin	2012/0247134	A1*	10/2012	Gurin ..... 62/129
2007/0161095	A1	7/2007	Gurin	2012/0247455	A1	10/2012	Gurin et al.
2007/0163261	A1	7/2007	Strathman	2012/0261090	A1	10/2012	Durmaz et al.
2007/0195152	A1	8/2007	Kawai et al.	2013/0019597	A1	1/2013	Kalina
2007/0204620	A1	9/2007	Pronske et al.	2013/0033037	A1	2/2013	Held et al.
2007/0227472	A1	10/2007	Takeuchi et al.	2013/0036736	A1	2/2013	Hart et al.
2007/0234722	A1	10/2007	Kalina	2013/0113221	A1	5/2013	Held
2007/0245733	A1	10/2007	Pierson et al.				
2007/0246206	A1	10/2007	Gong et al.				
2008/0000225	A1	1/2008	Kalina				
2008/0006040	A1	1/2008	Peterson et al.				
2008/0010967	A1	1/2008	Griffin et al.				
2008/0023666	A1	1/2008	Gurin				
2008/0053095	A1	3/2008	Kalina				
2008/0066470	A1	3/2008	MacKnight				
2008/0135253	A1	6/2008	Vinegar et al.				
2008/0163625	A1	7/2008	O'Brien				
2008/0173450	A1	7/2008	Goldberg et al.				
2008/0211230	A1	9/2008	Gurin				
2008/0250789	A1	10/2008	Myers et al.				
2008/0252078	A1	10/2008	Myers				
2008/0282715	A1*	11/2008	Aue et al. .... 62/159				
2009/0021251	A1	1/2009	Simon				
2009/0085709	A1	4/2009	Meinke				
2009/0107144	A1	4/2009	Moghtaderi et al.				
2009/0139234	A1	6/2009	Gurin				
2009/0139781	A1	6/2009	Straubel				
2009/0173337	A1	7/2009	Tamaura et al.				
2009/0173486	A1	7/2009	Copeland				
2009/0180903	A1	7/2009	Martin et al.				
2009/0205892	A1	8/2009	Jensen et al.				
2009/0211251	A1	8/2009	Petersen et al.				
2009/0211253	A1	8/2009	Radcliff et al.				
2009/0266075	A1	10/2009	Westmeier et al.				
2009/0293503	A1	12/2009	Vandor				
2010/0024421	A1	2/2010	Litwin				
2010/0077792	A1	4/2010	Gurin				
2010/0083662	A1	4/2010	Kalina				
2010/0102008	A1	4/2010	Hedberg				
2010/0122533	A1	5/2010	Kalina				
2010/0146949	A1	6/2010	Stobart et al.				
2010/0146973	A1	6/2010	Kalina				
2010/0156112	A1	6/2010	Held et al.				
2010/0162721	A1	7/2010	Welch et al.				
2010/0205962	A1	8/2010	Kalina				
2010/0218513	A1	9/2010	Vaisman et al.				
2010/0218930	A1	9/2010	Proeschel				
2010/0263380	A1	10/2010	Biederman et al.				
2010/0287934	A1	11/2010	Lynn et al.				
2010/0300093	A1	12/2010	Doty				
2010/0326076	A1	12/2010	Ast et al.				
2011/0027064	A1	2/2011	Pal et al.				
2011/0030404	A1	2/2011	Gurin				
2011/0048012	A1	3/2011	Ernst et al.				
2011/0061384	A1	3/2011	Held et al.				
2011/0061387	A1	3/2011	Held et al.				
2011/0088399	A1	4/2011	Briesch et al.				
2011/0179799	A1	7/2011	Allam et al.				
2011/0185729	A1	8/2011	Held				
2011/0192163	A1	8/2011	Kasuya				
2011/0203278	A1	8/2011	Kopecek et al.				
2011/0259010	A1	10/2011	Bronicki et al.				
2011/0299972	A1	12/2011	Morris et al.				
2011/0308253	A1	12/2011	Ritter				

## FOREIGN PATENT DOCUMENTS

CN	1432102	A	7/2003
CN	101614139	A	12/2009
CN	202055876	U	11/2011
CN	202544943	U	11/2012
CN	202718721	U	2/2013
DE	2632777	A1	2/1977
DE	199906087		8/2000
DE	10052993	A1	5/2002
EP	1977174	A2	10/2008
EP	1998013	A2	12/2008
EP	2419621	A1	2/2012
EP	2446122	A1	5/2012
EP	2478201	A1	7/2012
EP	2500530	A1	9/2012
EP	2550436		1/2013
GB	856985	A	12/1960
GB	2010974	A	7/1979
GB	2075608		11/1981
JP	58193051		11/1983
JP	60040707	A	3/1985
JP	61-152914	A	7/1986
JP	01-240705	A	9/1989
JP	05-321612	A	12/1993
JP	06-331225	A	11/1994
JP	08028805	A	2/1996
JP	09-100702	A	4/1997
JP	2641581	B2	5/1997
JP	09-209716	A	8/1997
JP	2858750	B2	12/1998
JP	H11270352		5/1999
JP	2000257407	A	9/2000
JP	2001-193419	A	7/2001
JP	2002-097965	A	4/2002
JP	2003529715	A	10/2003
JP	2004-239250	A	8/2004
JP	2004-332626	A	11/2004
JP	2005030727	A	2/2005
JP	2005-533972	A1	11/2005
JP	2006037760	A	2/2006
JP	2006177266	A	7/2006
JP	2007-198200	A	9/2007
JP	4343738	B2	10/2009
JP	2011-017268	A	1/2011
KR	100191080		6/1999
KR	10-2007-0086244	A	8/2007
KR	10-0766101	B1	10/2007
KR	10-0844634	A	7/2008
KR	10-20100067927	A	6/2010
KR	1020110018769	A	2/2011
KR	1069914	B1	9/2011
KR	1103549	B1	1/2012
KR	10-2012-0058582	A	6/2012
KR	2012-0068670	A	6/2012
KR	2012-0128753	A	6/2012
KR	2012-0128753	A	11/2012
KR	2012-0128755	A	11/2012
WO	WO 91/05145	A1	4/1991
WO	9609500		3/1996

(56)

**References Cited**

## FOREIGN PATENT DOCUMENTS

WO	0071944	A1	11/2000
WO	WO 01/44658	A1	6/2001
WO	WO 2006/060253		6/2006
WO	WO 2006/137957	A1	12/2006
WO	WO 2007/056241	A2	5/2007
WO	2007082103		7/2007
WO	WO 2007/079245	A2	7/2007
WO	WO 2007082103	A2 *	7/2007
WO	WO 2007/112090	A2	10/2007
WO	WO 2008/039725	A2	4/2008
WO	2008101711	A2	8/2008
WO	wo 2009/045196	A1	4/2009
WO	WO 2009/058992	A2	5/2009
WO	2010083198	A1	7/2010
WO	WO 2010/074173	A1	7/2010
WO	WO 2010/121255	A1	10/2010
WO	WO 2010/126980	A2	11/2010
WO	WO 2010/151560	A1	12/2010
WO	2011017450		2/2011
WO	2011017599		2/2011
WO	WO 2011/017476	A1	2/2011
WO	WO 2011/034984	A1	3/2011
WO	WO 2011/094294	A2	8/2011
WO	WO 2011/119650	A2	9/2011
WO	WO 2012/074905	A2	6/2012
WO	WO 2012/074907	A2	6/2012
WO	WO 2012/074911	A2	6/2012
WO	WO 2012/074940	A2	6/2012
WO	WO 2013/055391	A1	4/2013
WO	WO 2013/059687	A1	4/2013
WO	WO 2013/059695	A1	4/2013
WO	WO 2013/070249	A1	5/2013
WO	WO 2013/074907	A1	5/2013

## OTHER PUBLICATIONS

CN Search Report for Application No. 201080050795.7, 2 pages.  
PCT/US2011/062198—Extended European Search Report dated May 6, 2014, 9 pages.  
PCT/US2011/062201—Extended European Search Report dated May 28, 2014, 8 pages.  
PCT/US2013/055547—Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority, or the Declaration dated Jan. 24, 2014, 11 pages.  
PCT/US2013/064470—Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority, or the Declaration dated Jan. 22, 2014, 10 pages.  
PCT/US2013/064471—Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority, or the Declaration dated Jan. 24, 2014, 10 pages.  
PCT/US2014/013154—International Search Report dated May 23, 2014, 4 pages.  
PCT/US2014/013170—Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority, or the Declaration dated May 9, 2014, 12 pages.  
PCT/US2014/023026—Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority, or the Declaration dated Jul. 22, 2014, 11 pages.  
PCT/US2014/023990—Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority, or the Declaration dated Jul. 17, 2014, 10 pages.  
PCT/US2014/026173—Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority, or the Declaration dated Jul. 9, 2014, 10 pages.  
Renz, Manfred, “The New Generation Kalina Cycle”, Contribution to the Conference: “Electricity Generation from Enhanced Geothermal Systems”, Sep. 14, 2006, Strasbourg, France, 18 pages.  
Thorin, Eva, “Power Cycles with Ammonia-Water Mixtures as Working Fluid”, Doctoral Thesis, Department of Chemical Engineer-

ing and Technology Energy Processes, Royal Institute of Technology, Stockholm, Sweden, 2000, 66 pages.  
PCT/US2010/044476—International Search Report and Written Opinion mailed Sep. 29, 2010.  
PCT/US2010/044681—International Search Report and Written Opinion mailed Oct. 7, 2010.  
Alpy, N., et al., “French Atomic Energy Commission views as regards SCO<sub>2</sub> Cycle Development priorities and related R&D approach,” Presentation, Symposium on SCO<sub>2</sub> Power Cycles, Apr. 29-30, 2009, Troy, NY, 20 pages.  
Angelino, G., and Invernizzi, C.M., “Carbon Dioxide Power Cycles using Liquid Natural Gas as Heat Sink”, Applied Thermal Engineering Mar. 3, 2009, 43 pages.  
Bryant, John C., Saari, Henry, and Zanganeh, Kourosh, “An Analysis and Comparison of the Simple and Recompression Supercritical CO<sub>2</sub> Cycles” Supercritical CO<sub>2</sub> Power Cycle Symposium, May 24-25, 2011, Boulder, CO, 8 pages.  
Chapman, Daniel J., Arias, Diego A., “An Assessment of the Supercritical Carbon Dioxide Cycle for Use in a Solar Parabolic Trough Power Plant”, Presentation, Abengoa Solar, Apr. 29-30, 2009, Troy, NY, 20 pages.  
Chapman, Daniel J., Arias, Diego A., “An Assessment of the Supercritical Carbon Dioxide Cycle for Use in a Solar Parabolic Trough Power Plant”, Paper, Abengoa Solar, Apr. 29-30, 2009, Troy, NY, 5 pages.  
Chen, Yang, Lundqvist, P., Johansson, A., Platell, P., “A Comparative Study of the Carbon Dioxide Transcritical Power Cycle Compared with an Organic Rankine Cycle with R123 as Working Fluid in Waste Heat Recovery”, Science Direct, Applied Thermal Engineering, Jun. 12, 2006, 6 pages.  
Chen, Yang, “Thermodynamic Cycles Using Carbon Dioxide as Working Fluid”, Doctoral Thesis, School of Industrial Engineering and Management, Stockholm, Oct. 2011, 150 pages., (3 parts).  
Chordia, Lalit, “Optimizing Equipment for Supercritical Applications”, Thar Energy LLC, Supercritical CO<sub>2</sub> Power Cycle Symposium, May 24-25, 2011, Boulder, CO, 7 pages.  
Combs, Osie V., “An Investigation of the Supercritical CO<sub>2</sub> Cycle (Feher cycle) for Shipboard Application”, Massachusetts Institute of Technology, May 1977, 290 pages.  
Di Bella, Francis A., “Gas Turbine Engine Exhaust Waste Heat Recovery Navy Shipboard Module Development”, Supercritical CO<sub>2</sub> Power Cycle Symposium, May 24-25, 2011, Boulder, CO, 8 pages.  
Dostal, V., et al., A Supercritical Carbon Dioxide Cycle for Next Generation Nuclear Reactors, Mar. 10, 2004, 326 pages., (7 parts).  
Dostal, Vaclav and Kulhanek, Martin, “Research on the Supercritical Carbon Dioxide Cycles in the Czech Republic”, Czech Technical University in Prague, Symposium on SCO<sub>2</sub> Power Cycles, Apr. 29-30, 2009, Troy, NY, 8 pages.  
Dostal, Vaclav, and Dostal, Jan, “Supercritical CO<sub>2</sub> Regeneration Bypass Cycle—Comparison to Traditional Layouts”, Supercritical CO<sub>2</sub> Power Cycle Symposium, May 24-25, 2011, Boulder, CO, 5 pages.  
Eisemann, Kevin, and Fuller, Robert L., “Supercritical CO<sub>2</sub> Brayton Cycle Design and System Start-up Options”, Barber Nichols, Inc., Paper, Supercritical CO<sub>2</sub> Power Cycle Symposium, May 24-25, 2011, Boulder, CO, 7 pages.  
Eisemann, Kevin, and Fuller, Robert L., “Supercritical CO<sub>2</sub> Brayton Cycle Design and System Start-up Options”, Presentation, Supercritical CO<sub>2</sub> Power Cycle Symposium, May 24-25, 2011, Boulder, CO, 11 pages.  
Feher, E.G., et al., “Investigation of Supercritical (Feher) Cycle”, Astropower Laboratory, Missile & Space Systems Division, Oct. 1968, 152 pages.  
Fuller, Robert L., and Eisemann, Kevin, “Centrifugal Compressor Off-Design Performance for Super-Critical CO<sub>2</sub>”, Barber Nichols, Inc. Presentation, Supercritical CO<sub>2</sub> Power Cycle Symposium, May 24-25, 2011, Boulder, CO, 20 pages.  
Fuller, Robert L., and Eisemann, Kevin, “Centrifugal Compressor Off-Design Performance for Super-Critical CO<sub>2</sub>”, Paper, Supercritical CO<sub>2</sub> Power Cycle Symposium, May 24-25, 2011, Boulder, CO, 12 pages.

(56)

**References Cited****OTHER PUBLICATIONS**

- Gokhstein, D.P. and Verkhivker, G.P. "Use of Carbon Dioxide as a Heat Carrier and Working Substance in Atomic Power Stations", Soviet Atomic Energy, Apr. 1969, vol. 26, Issue 4, pp. 430-432.
- Gokhstein, D.P.; Taubman, E.I.; Konyaeva, G.P., "Thermodynamic Cycles of Carbon Dioxide Plant with an Additional Turbine After the Regenerator", Energy Citations Database, Mar. 1973, 1 Page, Abstract only.
- Hejzlar, P. et al., "Assessment of Gas Cooled Gas Reactor with Indirect Supercritical CO<sub>2</sub> Cycle" Massachusetts Institute of Technology, Jan. 2006, 10 pages.
- Hoffman, John R., and Feher, E.G., "150 kwe Supercritical Closed Cycle System", Transactions of the ASME, Jan. 1971, pp. 70-80.
- Jeong, Woo Seok, et al., "Performance of S-CO<sub>2</sub> Brayton Cycle with Additive Gases for SFR Application", Korea Advanced Institute of Science and Technology, Supercritical CO<sub>2</sub> Power Cycle Symposium, May 24-25, 2011, Boulder, CO, 5 pages.
- Johnson, Gregory A., & McDowell, Michael, "Issues Associated with Coupling Supercritical CO<sub>2</sub> Power Cycles to Nuclear, Solar and Fossil Fuel Heat Sources", Hamilton Sundstrand, Energy Space & Defense-Rocketdyne, Apr. 29-30, 2009, Troy, NY, Presentation, 18 pages.
- Kawakubo, Tomoki, "Unsteady Roto-Stator Interaction of a Radial-Inflow Turbine with Variable Nozzle Vanes", ASME Turbo Expo 2010: Power for Land, Sea, and Air; vol. 7: Turbomachinery, Parts A, B, and C; Glasgow, UK, Jun. 14-18, 2010, Paper No. GT2010-23677, pp. 2075-2084, (1 page, Abstract only).
- Kulhanek, Martin, "Thermodynamic Analysis and Comparison of S-CO<sub>2</sub> Cycles", Presentation, Czech Technical University in Prague, Supercritical CO<sub>2</sub> Power Cycle Symposium, May 24-25, 2011, Boulder, CO, 14 pages.
- Kulhanek, Martin, "Thermodynamic Analysis and Comparison of S-CO<sub>2</sub> Cycles", Paper, Czech Technical University in Prague, Supercritical CO<sub>2</sub> Power Cycle Symposium, May 24-25, 2011, Boulder, CO, 7 pages.
- Kulhanek, Martin, and Dostal, Vaclav, "Supercritical Carbon Dioxide Cycles Thermodynamic Analysis and Comparison", Abstract, Faculty Conference held in Prague, Mar. 24, 2009, 13 pages.
- Ma, Zhiwen and Turchi, Craig S., "Advanced Supercritical Carbon Dioxide Power Cycle Configurations for Use in Concentrating Solar Power Systems", National Renewable Energy Laboratory, Supercritical CO<sub>2</sub> Power Cycle Symposium, May 24-25, 2011, Boulder, CO, 4 pages.
- Moiseyev, Anton, and Sienicki, Jim, "Investigation of Alternative Layouts for the Supercritical Carbon Dioxide Brayton Cycle for a Sodium-Cooled Fast Reactor", Supercritical CO<sub>2</sub> Power Cycle Symposium, Troy, NY, Apr. 29, 2009, 26 pages.
- Munoz De Escalona, Jose M., "The Potential of the Supercritical Carbon Dioxide Cycle in High Temperature Fuel Cell Hybrid Systems", Paper, Thermal Power Group, University of Seville, Supercritical CO<sub>2</sub> Power Cycle Symposium, May 24-25, 2011, Boulder, CO, 6 pages.
- Munoz De Escalona, Jose M., et al., "The Potential of the Supercritical Carbon Dioxide Cycle in High Temperature Fuel Cell Hybrid Systems", Presentation, Thermal Power Group, University of Seville, Supercritical CO<sub>2</sub> Power Cycle Symposium, May 24-25, 2011, Boulder, CO, 19 pages.
- Muto, Y., et al., "Application of Supercritical CO<sub>2</sub> Gas Turbine for the Fossil Fired Thermal Plant", Journal of Energy and Power Engineering, Sep. 30, 2010, vol. 4, No. 9, 9 pages.
- Muto, Yasushi, and Kato, Yasuyoshi, "Optimal Cycle Scheme of Direct Cycle Supercritical CO<sub>2</sub> Gas Turbine for Nuclear Power Generation Systems", International Conference on Power Engineering-2007, Oct. 23-27, 2007, Hangzhou, China, pp. 86-87.
- Noriega, Bahamonde J.S., "Design Method for s-CO<sub>2</sub> Gas Turbine Power Plants", Master of Science Thesis, Delft University of Technology, Oct. 2012, 122 pages., (3 parts).
- Oh, Chang, et al., "Development of a Supercritical Carbon Dioxide Brayton Cycle: Improving PBR Efficiency and Testing Material Compatibility", Presentation, Nuclear Energy Research Initiative Report, Oct. 2004, 38 pages.
- Oh, Chang, et al., "Development of a Supercritical Carbon Dioxide Brayton Cycle: Improving VHTR Efficiency and Testing Material Compatibility", Presentation, Nuclear Energy Research Initiative Report, Final Report, Mar. 2006, 97 pages.
- Parma, Ed, et al., "Supercritical CO<sub>2</sub> Direct Cycle Gas Fast Reactor (SC-GFR) Concept" Presentation for Supercritical CO<sub>2</sub> Power Cycle Symposium, May 24-25, 2011, Boulder, CO, 40 pages.
- Parma, Ed, et al., "Supercritical CO<sub>2</sub> Direct Cycle Gas Fast Reactor (SC-GFR) Concept", Supercritical CO<sub>2</sub> Power Cycle Symposium, May 24-25, 2011, Boulder, CO, 9 pages.
- Parma, Edward J., et al., "Supercritical CO<sub>2</sub> Direct Cycle Gas Fast Reactor (SC-GFR) Concept", Presentation, Sandia National Laboratories, May 2011, 55 pages.
- PCT/US2006/049623 (EPS-020PCT)—Written Opinion of ISA dated Jan. 4, 2008, 4 pages.
- PCT/US2007/001120 (EPS-019PCT)—International Search Report dated Apr. 25, 2008, 7 pages.
- PCT/US2007/079318 (EPS-021PCT)—International Preliminary Report on Patentability dated Jul. 7, 2008, 5 pages.
- PCT/US2010/031614 (EPS-014)—International Search Report dated Jul. 12, 2010, 3 pages.
- PCT/US2010/031614 (EPS-14)—International Preliminary Report on Patentability dated Oct. 27, 2011, 9 pages.
- PCT/US2010/039559 (EPS-015)—International Preliminary Report on Patentability dated Jan. 12, 2012, 7 pages.
- PCT/US2010/039559 (EPS-015)—Notification of Transmittal of the International Search Report and Written Opinion of the International Searching Authority, or the Declaration dated Sep. 1, 2010, 6 pages.
- PCT/US2010/044681 (EPS-016)—International Preliminary Report on Patentability dated Feb. 16, 2012, 9 pages.
- PCT/US2010/049042 (EPS-008)—International Search Report and Written Opinion dated Nov. 17, 2010, 11 pages.
- PCT/US2010/049042 (EPS-008)—International Preliminary Report on Patentability dated Mar. 29, 2012, 18 pages.
- PCT/US2011/029486 (EPS-002)—International Preliminary Report on Patentability dated Sep. 25, 2012, 6 pages.
- PCT/US2011/029486 (EPS-002)—International Search Report and Written Opinion dated Nov. 16, 2011, 9 pages.
- PCT/US2011/062266 (EPS-069)—International Search Report and Written Opinion dated Jul. 9, 2012, 12 pages.
- PCT/US2011/062198 (EPS-070)—International Search Report and Written Opinion dated Jul. 2, 2012, 9 pages.
- PCT/US2011/062201 (EPS-071)—International Search Report and Written Opinion dated Jun. 26, 2012, 9 pages.
- PCT/US2011/062204 (EPS-072)—International Search Report dated Nov. 1, 2012, 10 pages.
- PCT/US2011/62207 (EPS-073)—International Search Report and Written Opinion dated Jun. 28, 2012, 7 pages.
- PCT/US2012/000470 (EPS-124)—International Search Report dated Mar. 8, 2013, 10 pages.
- PCT/US2012/061151 (EPS-125)—International Search Report and Written Opinion dated Feb. 25, 2013, 9 pages.
- PCT/US2012/061159 (EPS-126)—International Search Report dated Mar. 2, 2013, 10 pages.
- Persichilli, Michael, et al., "Supercritical CO<sub>2</sub> Power Cycle Developments and Commercialization: Why sCO<sub>2</sub> can Displace Steam" Echogen Power Systems LLC, Power-Gen India & Central Asia 2012, Apr. 19-21, 2012, New Delhi, India, 15 pages.
- Saari, Henry, et al., "Supercritical CO<sub>2</sub> Advanced Brayton Cycle Design", Presentation, Carleton University, Supercritical CO<sub>2</sub> Power Cycle Symposium, May 24-25, 2011, Boulder, CO, 21 pages.
- San Andres, Luis, "Start-Up Response of Fluid Film Lubricated Cryogenic Turbopumps (Preprint)", AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Cincinnati, OH, Jul. 8-11, 2007, 38 pages.
- Sarkar, J., and Bhattacharyya, Souvik, "Optimization of Recompression S-CO<sub>2</sub> Power Cycle with Reheating" Energy Conversion and Management 50 (May 17, 2009), pp. 1939-1945.

(56)

**References Cited**

**OTHER PUBLICATIONS**

Tom, Samsun Kwok Sun, "The Feasibility of Using Supercritical Carbon Dioxide as a Coolant for the Candu Reactor", The University of British Columbia, Jan. 1978, 156 pages.

VGB PowerTech Service GmbH, "CO<sub>2</sub> Capture and Storage", A VGB Report on the State of the Art, Aug. 25, 2004, 112 pages.

Vidhi, Rachana, et al., "Study of Supercritical Carbon Dioxide Power Cycle for Power Conversion from Low Grade Heat Sources", Presentation, University of South Florida and Oak Ridge National Laboratory, Supercritical CO<sub>2</sub> Power Cycle Symposium, May 24-25, 2011, Boulder, CO, 17 pages.

Vidhi, Rachana, et al., "Study of Supercritical Carbon Dioxide Power Cycle for Power Conversion from Low Grade Heat Sources", Paper, University of South Florida and Oak Ridge National Laboratory, Supercritical CO<sub>2</sub> Power Cycle Symposium, May 24-25, 2011, Boulder, CO, 8 pages.

Wright, Steven A., et al., "Modeling and Experimental Results for Condensing Supercritical CO<sub>2</sub> Power Cycles", Sandia Report, Jan. 2011, 47 pages.

Wright, Steven A., et al., "Supercritical CO<sub>2</sub> Power Cycle Development Summary at Sandia National Laboratories", May 24-25, 2011, (1 page, Abstract only).

Wright, Steven, "Mighty Mite", Mechanical Engineering, Jan. 2012, pp. 41-43.

Yoon, Ho Joon, et al., "Preliminary Results of Optimal Pressure Ratio for Supercritical CO<sub>2</sub> Brayton Cycle coupled with Small Modular Water Cooled Reactor", Presentation, Korea Advanced Institute of Science and Technology and Khalifa University of Science, Technology and Research, Boulder, CO, May 25, 2011, 18 pages.

Yoon, Ho Joon, et al., "Preliminary Results of Optimal Pressure Ratio for Supercritical CO<sub>2</sub> Brayton Cycle coupled with Small Modular Water Cooled Reactor", Paper, Korea Advanced Institute of Science and Technology and Khalifa University of Science, Technology and Research, May 24-25, 2011, Boulder, CO, 7 pages.

\* cited by examiner

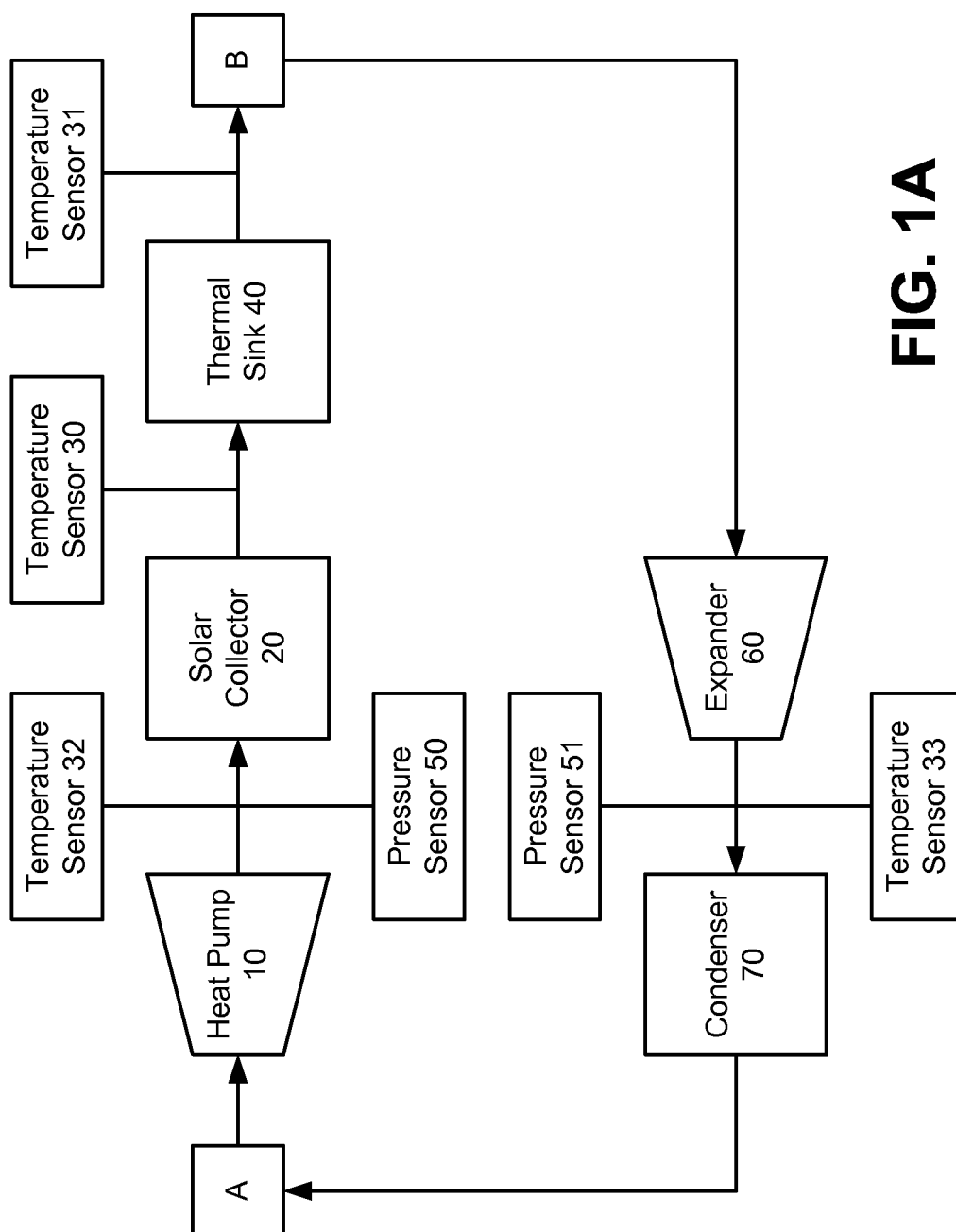


FIG. 1A

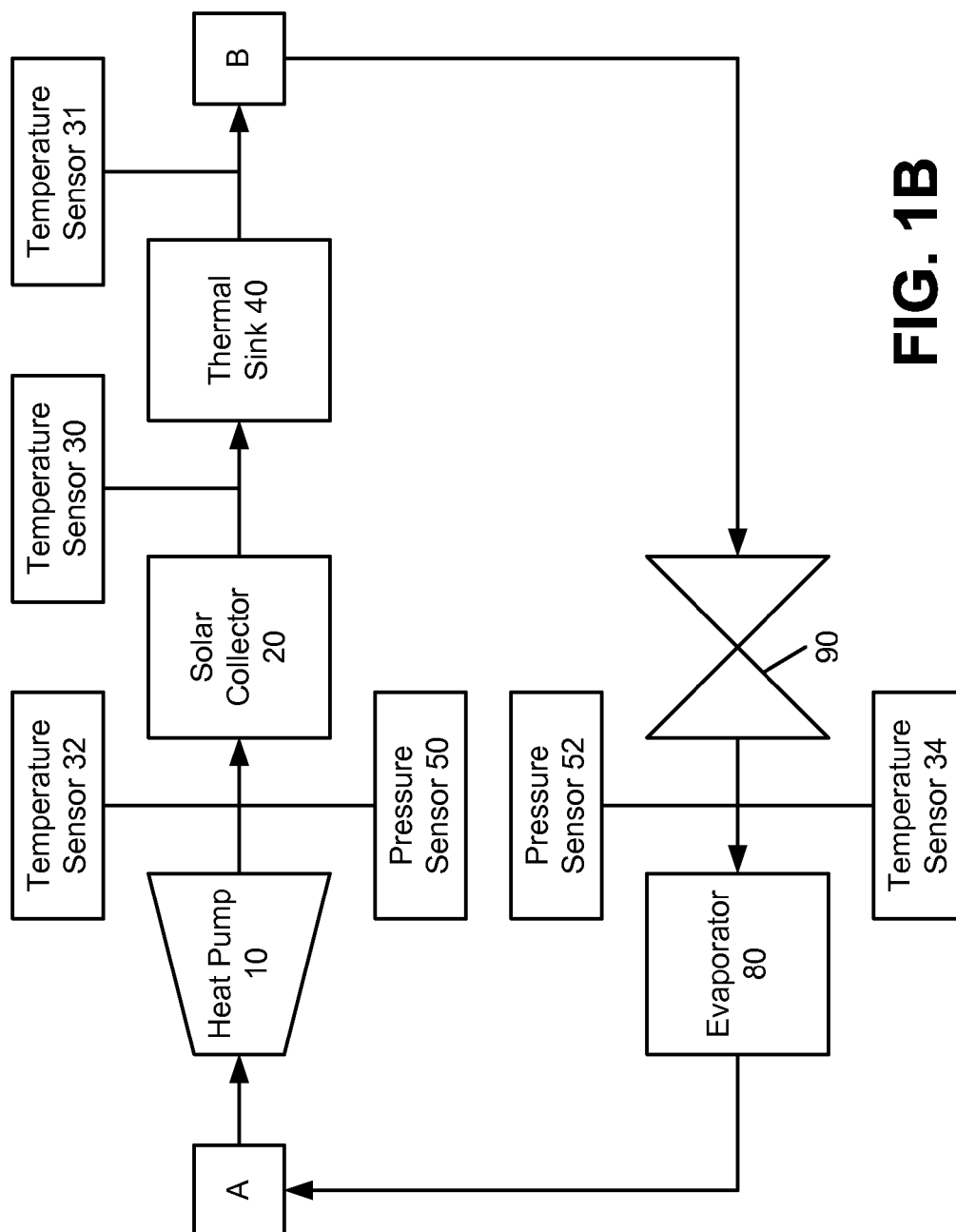


FIG. 1B

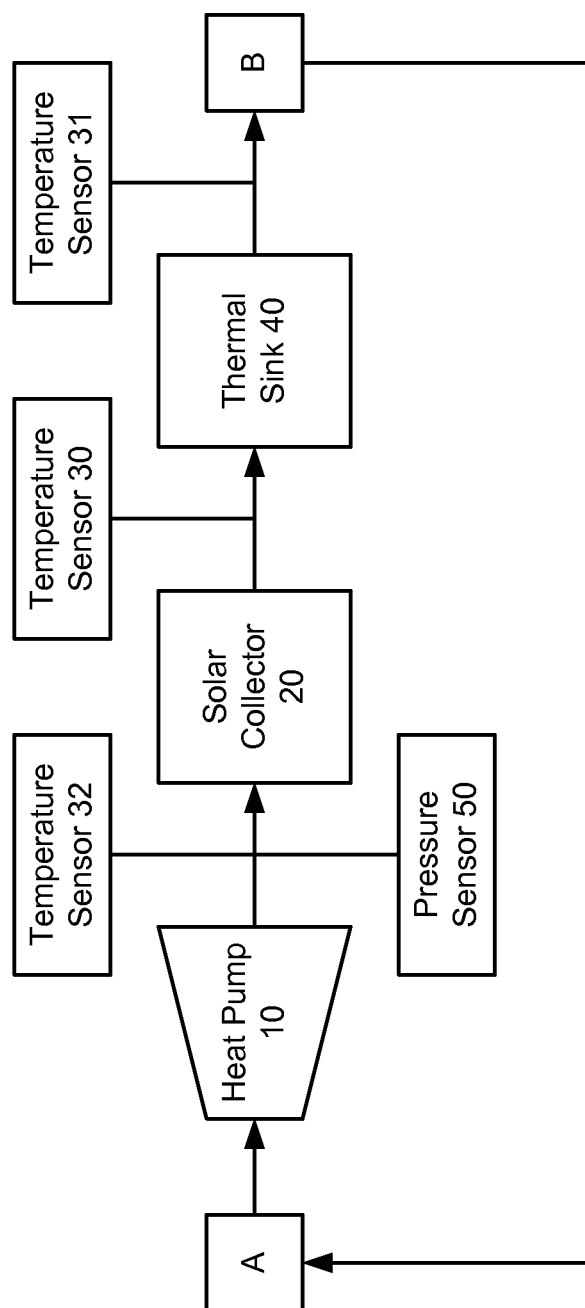
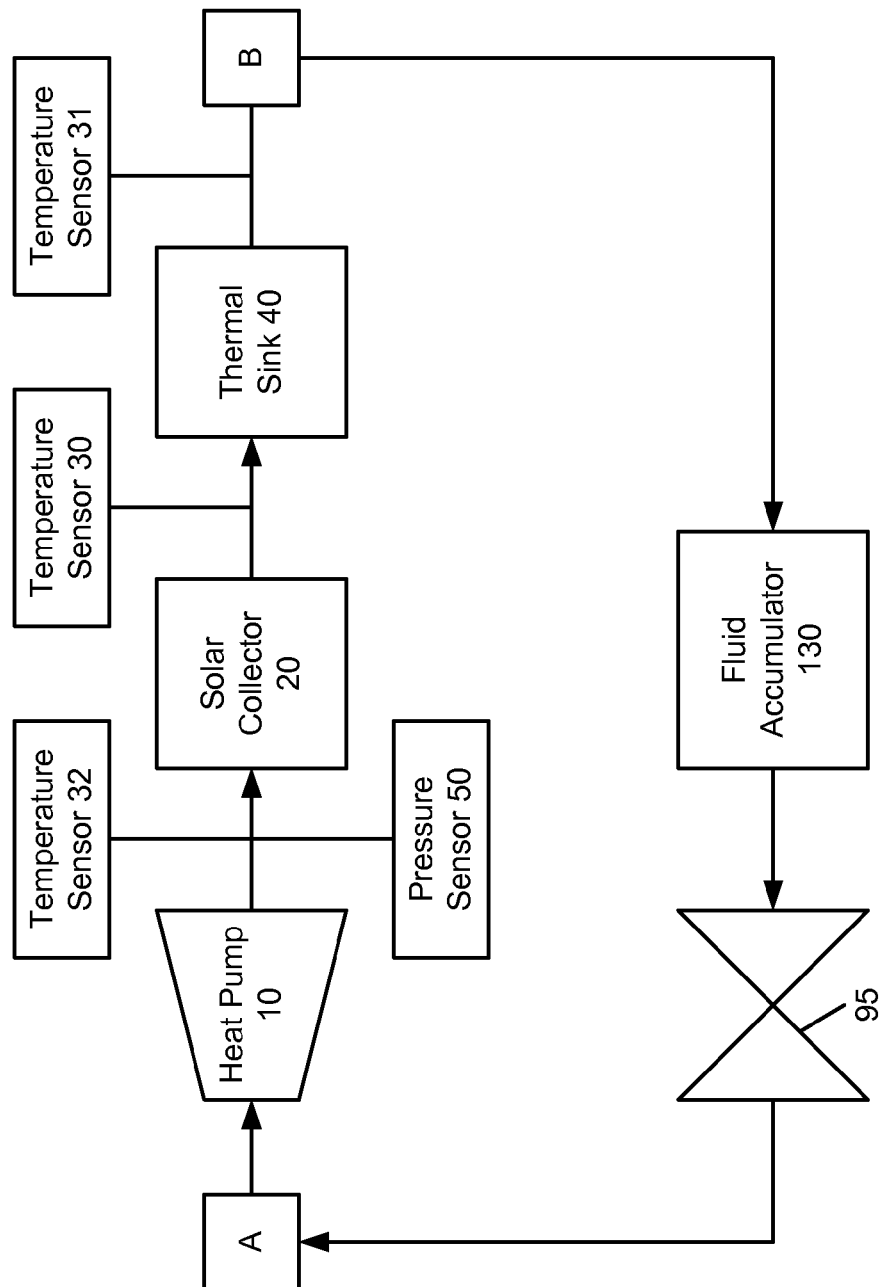
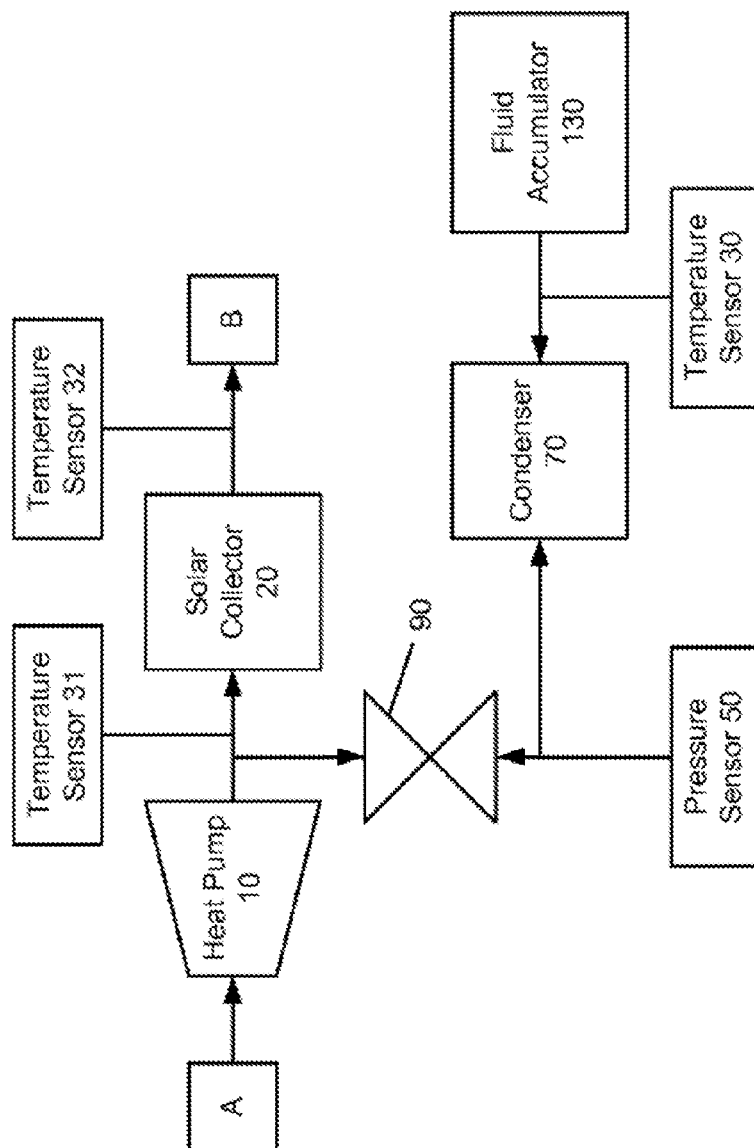


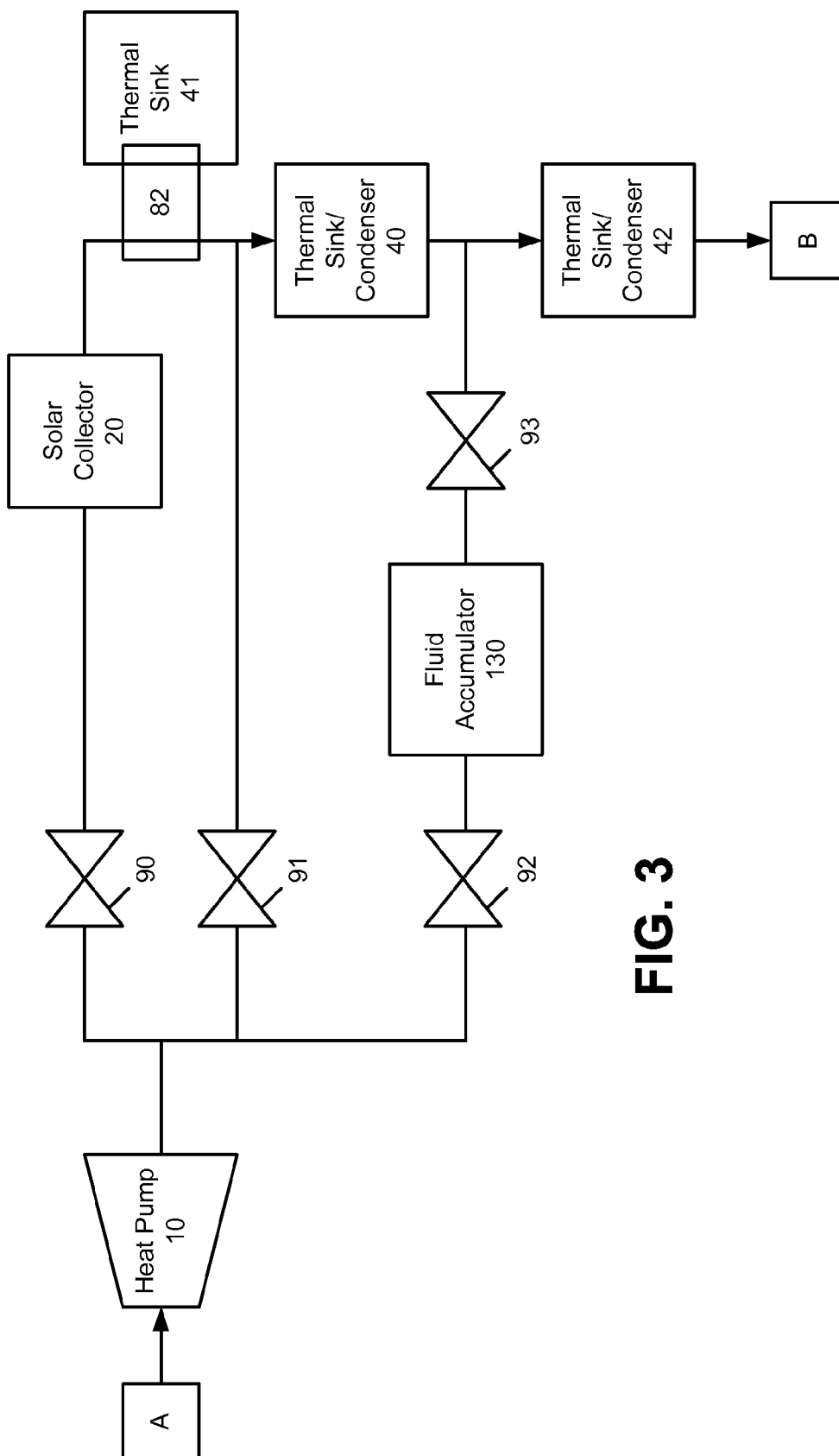
FIG. 1C



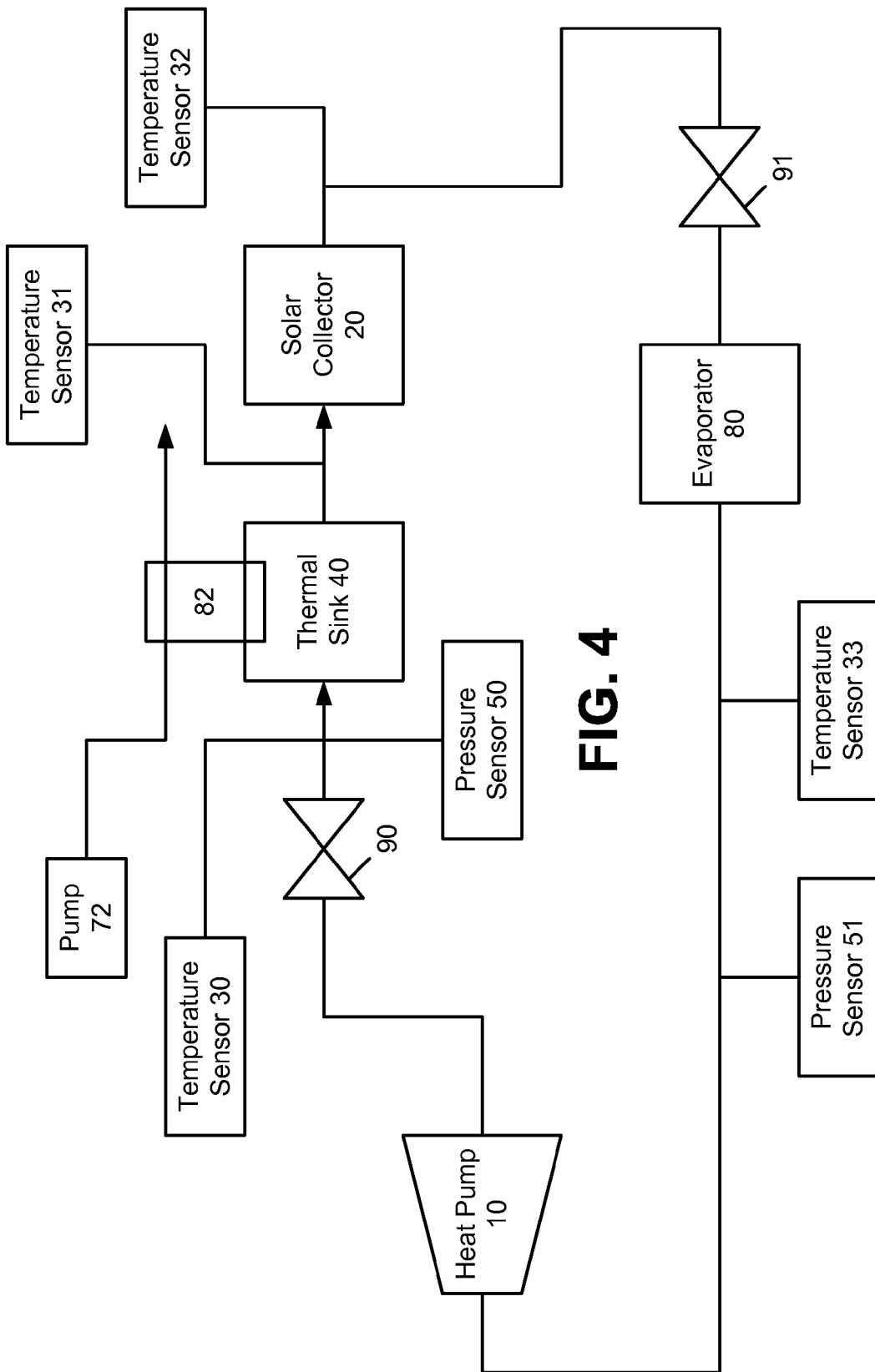
**FIG. 1D**

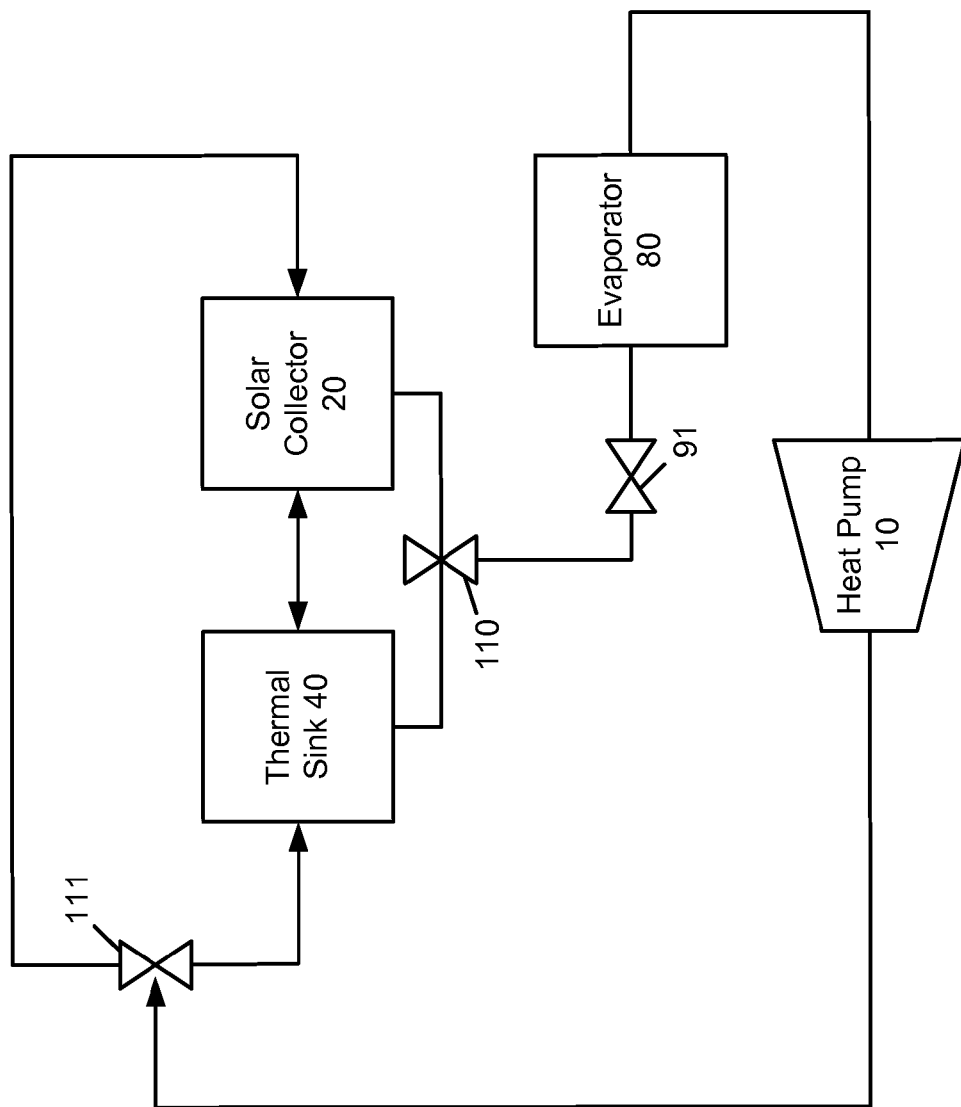


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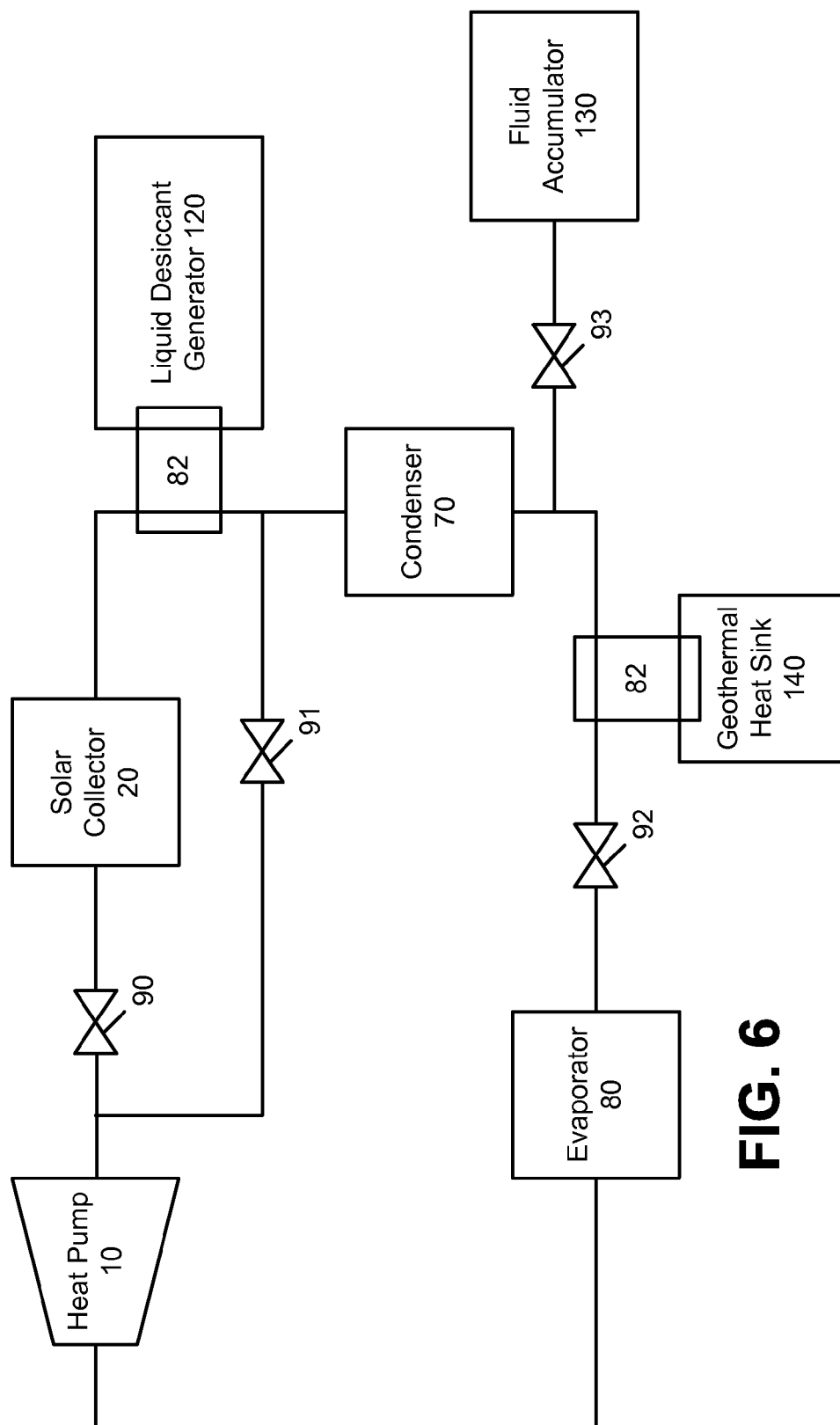


**FIG. 3**

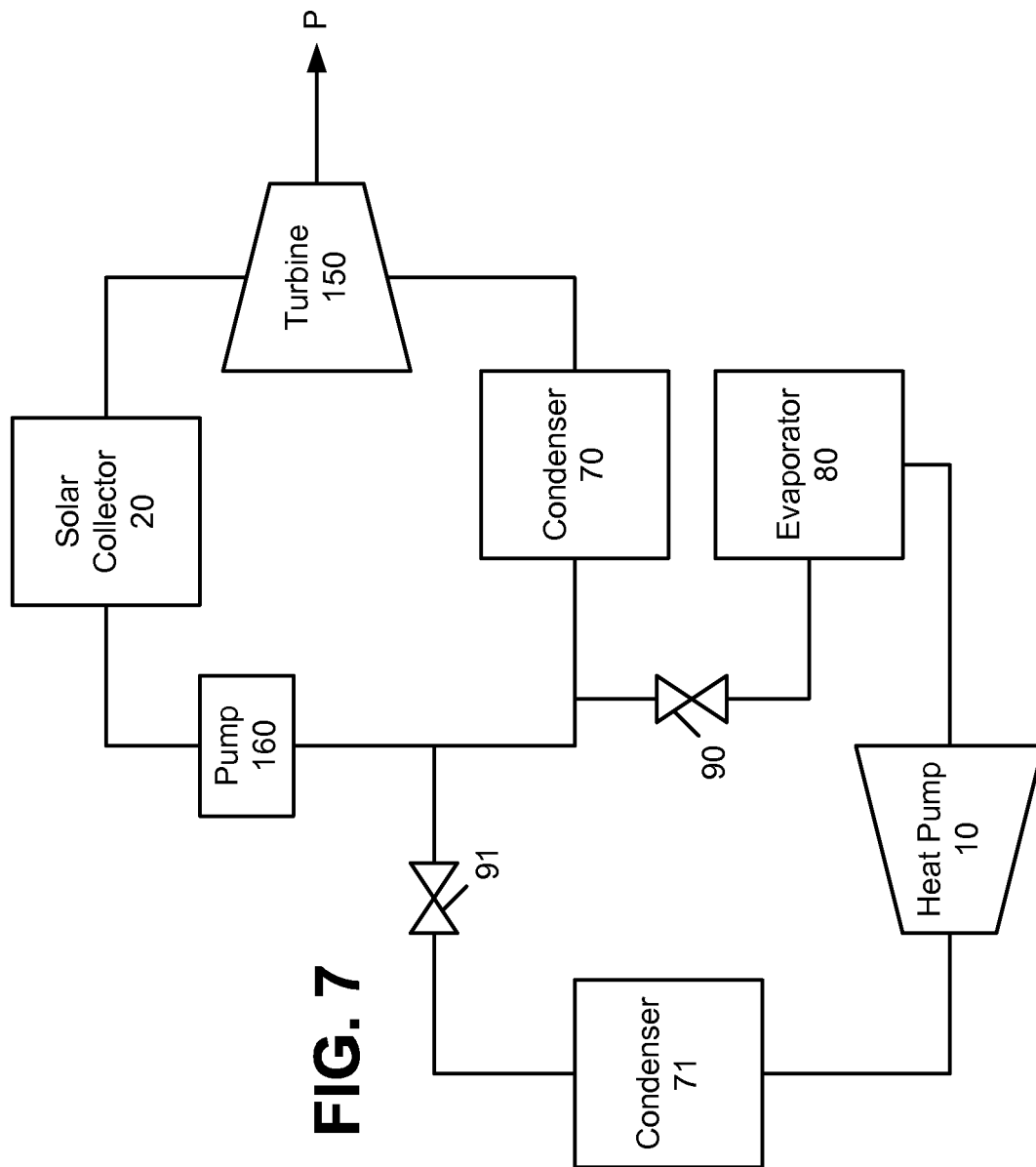




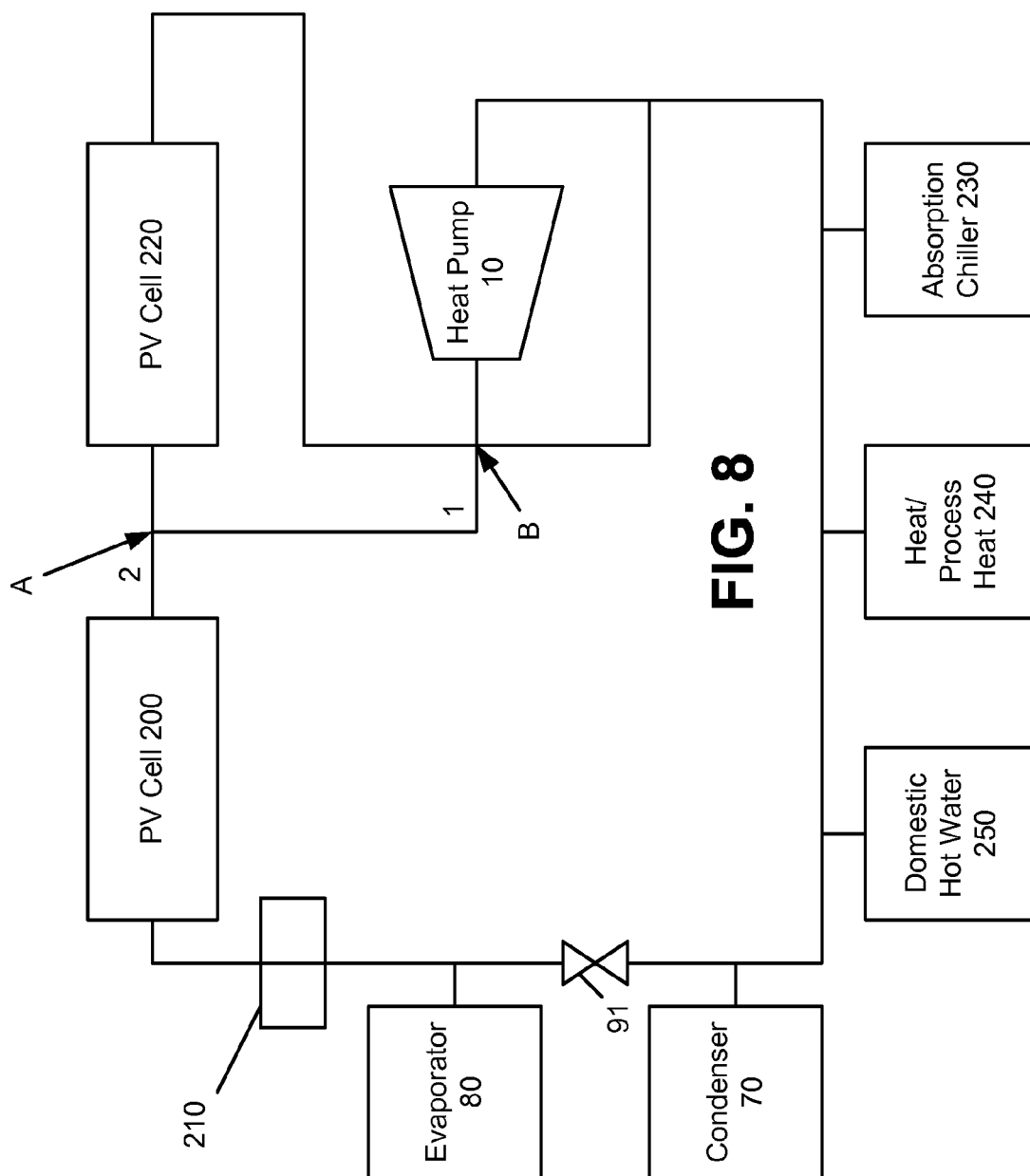
**FIG. 5**

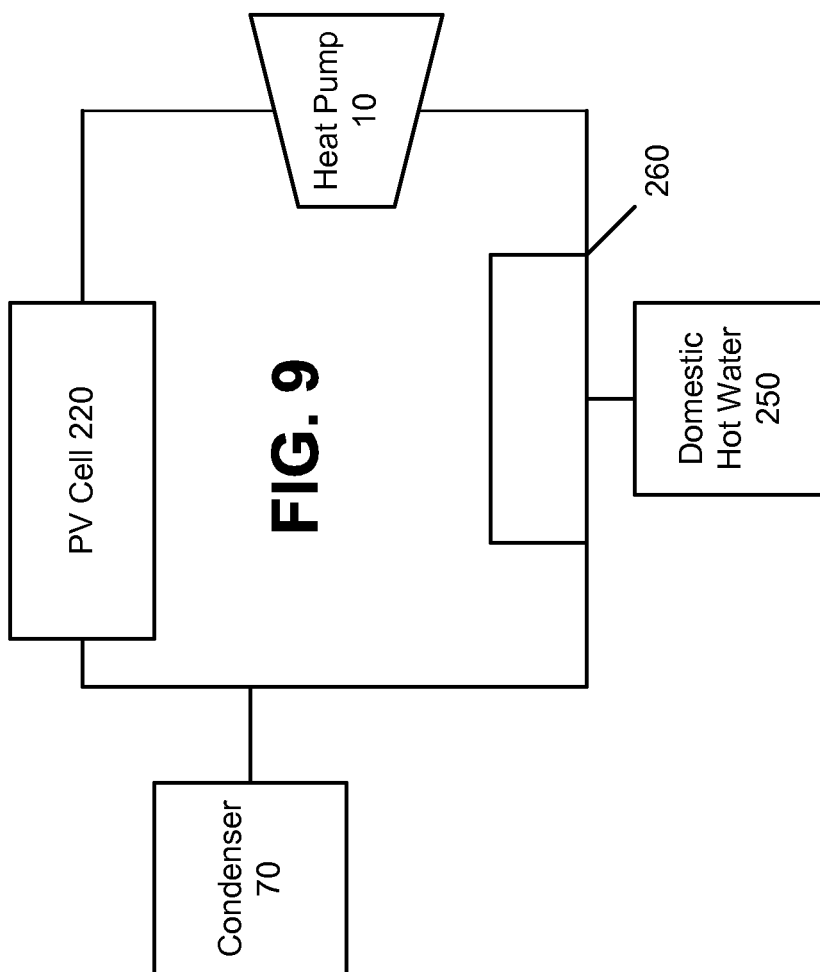


**FIG. 6**



**FIG. 7**





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**HEAT PUMP WITH INTEGRAL SOLAR COLLECTOR**

## RELATED APPLICATION DATA

This patent application claims priority to U.S. Provisional Patent Application No. 61/231,238, filed on Aug. 4, 2009 entitled "Heat Pump with Integral Solar Collector," the entirety of which is hereby incorporated by reference herein.

## FIELD OF THE INVENTION

The present invention generally relates to highly integrated solar collector with a heat pump. In all embodiments, the present invention utilizes the same working fluid within the primary solar collector as the heat pump.

## BACKGROUND OF THE INVENTION

Due to a variety of factors including, but not limited to, global warming issues, fossil fuel availability and environmental impacts, crude oil price and availability issues, alternative energy sources are becoming more popular today. One such source of alternative and/or renewable energy is solar energy. One such way to collect solar energy is to use a solar receiver to focus and convert solar energy into a desired form (e.g., thermal energy or electrical energy). Thermal energy harvested from the sun is known in the art to be utilized in absorption heat pumps, domestic hot water and industrial processes, power generating cycles through the heating of a secondary heat transfer fluid, power generating cycles through the direct heating of power generating working fluid such as steam, and for heating. Furthermore, it is recognized that a wide range of energy consumers can be supplied via electrical and/or thermal energy such as air conditioning, refrigeration, heating, industrial processes, and domestic hot water. Given this, solar collectors that function in efficient manners are desirable.

Traditional thermal activated processes effectively consider every unit of energy into the system. Furthermore by definition solar energy is a function of solar intensity and thus at the minimum is absent during the nighttime, unless significant thermal storage is utilized that is currently very expensive. Additionally, it is recognized in the art that vapor compressor heat pumps have coefficients of performance "COP" substantially higher than absorption heat pumps. And hot water heaters utilizing vapor compressor driven heat pumps also have substantially higher COPs as compared to direct heating of hot water having COPs less than unity. In addition, traditional solar collectors, particularly flat panel collectors, are temperature constrained due in large part to declining efficiencies as a function of temperature and the degradation of the working fluid which is often a mixture of a glycol and water. Solar collectors typically fall into the category of pump driven working fluid circulation or thermosiphon that respectively have the deficiency of requiring a pump or orientation of solar collector with respect to the "condenser".

Heat pumps also have significant limitations that limit temperature including the requirement for oil lubrication that would suffer oxidative destruction at the higher temperatures desired within heat pumps. Additionally, the working fluid in virtually all refrigerants is significantly expandable across a wide operating temperature range.

The combined limitations of each individual component being the solar collector and the heat pump presents significant

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challenges that are further exasperated when high integration using the same working fluid for both devices is realized.

## SUMMARY OF THE INVENTION

The present invention generally relates to highly integrated solar collector with a heat pump. In all embodiments, the present invention utilizes the same working fluid within the primary solar collector as the heat pump.

In one embodiment, the present invention relates to a heat pump system comprising: at least one working fluid; at least one heat pump having an inlet and an outlet designed to receive and utilize the at least one working fluid; at least one solar collector having an inlet and an outlet designed to receive and utilize the at least one working fluid, wherein the inlet of the at least one solar collector is in fluid communication via the at least one working fluid with the outlet of the at least one heat pump; and at least one thermal sink having an inlet and an outlet designed to receive and utilize the at least one working fluid, wherein the inlet of the at least one thermal sink is in fluid communication via the at least one working fluid with the outlet of the at least one solar collector, and wherein the outlet of the at least one thermal sink is in fluid communication via the at least one working fluid with the inlet of the at least one heat pump, wherein the heat pump system contains a first temperature sensor and a first pressure sensor in fluid communication with the at least one working fluid, the first temperature sensor and the first pressure sensor being located between the at least one heat pump and the at least one solar collector, wherein the heat pump system contains a second temperature sensor in fluid communication with the at least one working fluid, the second temperature sensor being located between the at least one solar collector and the at least one thermal sink, and wherein the heat pump system contains a third temperature sensor in fluid communication with the at least one working fluid, the third temperature sensor being located between the at least one thermal sink and the at least one heat pump.

In another embodiment, the present invention relates to a heat pump system comprising: at least one working fluid; at least one heat pump having an inlet and an outlet designed to receive and utilize the at least one working fluid; at least one solar collector having an inlet and an outlet designed to receive and utilize the at least one working fluid, wherein the inlet of the at least one solar collector is in fluid communication via the at least one working fluid with the outlet of the at least one heat pump; at least one thermal sink having an inlet and an outlet designed to receive and utilize the at least one working fluid, wherein the inlet of the at least one thermal sink is in fluid communication via the at least one working fluid with the outlet of the at least one solar collector; at least one expander having an inlet and an outlet designed to receive and utilize the at least one working fluid, wherein the inlet of the at least one expander is in fluid communication via the at least one working fluid with the outlet of the at least one thermal sink; and at least one condenser having an inlet and an outlet designed to receive and utilize the at least one working fluid, wherein the inlet of the at least one condenser is in fluid communication via the at least one working fluid with the outlet of the at least one expander, and wherein the outlet of the at least one condenser is in fluid communication via the at least one working fluid with the inlet of the at least one heat pump, wherein the heat pump system contains a first temperature sensor and a first pressure sensor in fluid communication with the at least one working fluid, the first temperature sensor and the first pressure sensor being located between the

In still another embodiment, the present invention relates to a heat pump system comprising: at least one working fluid; at least one heat pump having an inlet and an outlet designed to receive and utilize the at least one working fluid; at least one solar collector having an inlet and an outlet designed to receive and utilize the at least one working fluid, wherein the inlet of the at least one solar collector is in fluid communication via the at least one working fluid with the outlet of the at least one heat pump; at least one thermal sink having an inlet and an outlet designed to receive and utilize the at least one

In still another embodiment, the present invention relates to a heat pump system comprising: at least one working fluid; at least one heat pump having an inlet and an outlet designed to receive and utilize the at least one working fluid; at least one solar collector having an inlet and an outlet designed to receive and utilize the at least one working fluid, wherein the inlet of the at least one solar collector is in fluid communication via the at least one working fluid with the outlet of the at least one heat pump; and at least one working fluid inventory storage system, wherein the at least one working fluid inventory storage system is in fluid communication with both the at least one heat pump and the at least one solar collector, wherein the at least one working fluid inventory storage system is designed to working in a bi-directional manner, and wherein the at least one working fluid inventory storage system comprises: at least one bi-directional expansion valve having an inlet and an outlet designed to receive and utilize the at least one working fluid, wherein the inlet of the at least one bi-directional expansion valve is in fluid communication via the at least one working fluid with both the outlet of the at least one heat pump and the inlet of the at least one solar collector; at least one bi-directional condenser having an inlet and an outlet designed to receive and utilize the at least one working fluid, wherein the inlet of the at least one bi-directional condenser is in fluid communication via the at least one working fluid with the outlet of the at least one bi-directional expansion valve; and at least one bi-directional fluid accumulator having an inlet and an outlet designed to receive and utilize the at least one working fluid, wherein the inlet of the at least one bi-directional fluid accumulator is in fluid communication via the at least one working fluid with the outlet of the at least one bi-directional condenser, wherein the heat pump system contains a first temperature sensor in fluid communication with the at least one working fluid, the first temperature sensor being located between the at least one heat pump and the at least one solar collector, wherein the heat pump system contains a second temperature sensor in fluid communication with the at least one working fluid, the second temperature sensor being located downstream of the at least

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one solar collector, wherein the heat pump system contains a third temperature sensor in fluid communication with the at least one working fluid, the third temperature sensor being located between the at least one bi-directional expansion valve and the at least one bi-directional fluid accumulator, and wherein the heat pump system contains a first pressure sensor in fluid communication with the at least one working fluid, the first pressure sensor being located between the at least one bi-directional expansion valve and the at least one bi-directional fluid condenser.

In still another embodiment, the present invention relates to a heat pump system comprising: at least one working fluid; at least one heat pump having an inlet and an outlet designed to receive and utilize the at least one working fluid; at least one solar collector having an inlet and an outlet designed to receive and utilize the at least one working fluid, wherein the inlet of the at least one solar collector is in fluid communication via the at least one working fluid with the outlet of the at least one heat pump via at least one first valve; at least one first thermal sink/condenser having an inlet and an outlet designed to receive and utilize the at least one working fluid, wherein the inlet of the at least one first thermal sink/condenser is in fluid communication via the at least one working fluid with the outlet of the at least one heat pump via at least one second valve; at least one fluid accumulator having an inlet and an outlet designed to receive and utilize the at least one working fluid, wherein the inlet of the at least one fluid accumulator is in fluid communication via the at least one working fluid with the outlet of the at least one heat pump via at least one third valve; at least one thermal sink/heat exchanger combination having an inlet and an outlet designed to receive and utilize the at least one working fluid, wherein the inlet of the at least one thermal sink/heat exchanger combination is in thermal communication, or fluid communication, via the at least one working fluid with the outlet of the at least one solar collector, and wherein the outlet of the at least one thermal sink/heat exchanger combination is in thermal communication, or fluid communication, via the at least one working fluid with the inlet of the at least one first thermal sink/condenser; and at least one second thermal sink/condenser having an inlet and an outlet designed to receive and utilize the at least one working fluid, wherein the inlet of the at least one second thermal sink/condenser is in fluid communication via the at least one working fluid with the outlet of the at least one first thermal sink/condenser, and wherein the inlet of the at least one second thermal sink/condenser is in fluid communication via the at least one working fluid with the outlet of the at least one fluid accumulator pump via at least one fourth valve.

In still another embodiment, the present invention relates to a heat pump system comprising: at least one working fluid; at least one heat pump having an inlet and an outlet designed to receive and utilize the at least one working fluid; at least one thermal sink having an inlet and an outlet designed to receive and utilize the at least one working fluid, wherein the inlet of the at least one thermal sink is in fluid communication via the at least one working fluid with the outlet of the at least one heat pump via at least one first valve; at least one heat exchanger/pump combination, wherein the at least one heat exchanger/pump combination is in thermal communication, or fluid communication, with the at least one thermal sink; at least one solar collector having an inlet and an outlet designed to receive and utilize the at least one working fluid, wherein the inlet of the at least one solar collector is in fluid communication via the at least one working fluid with the outlet of the at least one thermal sink; and at least one evaporator having an inlet and an outlet designed to receive and utilize the at least one working fluid, wherein the inlet of the at least one evapo-

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rator is in fluid communication via the at least one working fluid with the outlet of the at least one solar collector via at least one second valve, and wherein the outlet of the at least one evaporator is in fluid communication via the at least one working fluid with the inlet of the at least one heat pump, wherein the heat pump system contains a first temperature sensor and a first pressure sensor in fluid communication with the at least one working fluid, the first temperature sensor and the first pressure sensor being located between the at least one heat pump and the at least thermal sink, wherein the heat pump system contains a second temperature sensor in fluid communication with the at least one working fluid, the second temperature sensor being located between the least one thermal sink and the at least one solar collector, wherein the heat pump system contains a third temperature sensor in fluid communication with the at least one working fluid, the third temperature sensor being located between the at least one solar collection and the at least one evaporator, and wherein the heat pump system contains a fourth temperature sensor and a second pressure sensor in fluid communication with the at least one working fluid, the fourth temperature sensor and the second pressure sensor being located between the at least one evaporator and the at least one heat pump.

In still another embodiment, the present invention relates to a heat pump system comprising: at least one working fluid; at least one heat pump designed to receive and utilize the at least one working fluid; at least one thermal sink designed to receive and utilize the at least one working fluid, wherein the at least one thermal sink is in fluid communication via the at least one working fluid with the at least one heat pump via at least one first bi-directional valve; at least one solar collector designed to receive and utilize the at least one working fluid, wherein the at least one solar collector is in fluid communication via the at least one working fluid with the at least one thermal sink via a bi-directional connection, and wherein the at least one solar collection is in fluid communication via the at least one working fluid with the at least one heat pump via the first bi-directional valve; and at least one evaporator designed to receive and utilize the at least one working fluid, wherein the at least one evaporator is in fluid communication via the at least one working fluid with both the at least one thermal sink and the at least one solar collector via the combination of at least one second bi-directional valve and at least one valve, and wherein the at least one evaporator is in fluid communication via the at least one working fluid with the at least one heat pump.

In still another embodiment, the present invention relates to a heat pump system comprising: at least one working fluid; at least one heat pump designed to receive and utilize the at least one working fluid; at least one solar collector designed to receive and utilize the at least one working fluid, wherein the at least one solar collector is in fluid communication via the at least one working fluid with the at least heat pump via at least one first valve; at least one liquid desiccant generator/heat exchanger combination designed to receive and utilize the at least one working fluid, wherein the at least one liquid desiccant generator/heat exchanger combination is in thermal communication, or fluid communication, via the working fluid with the at least one solar collector; at least one condenser designed to receive and utilize the at least one working fluid, wherein the at least one condenser is in fluid communication via the at least one working fluid with the at least one heat pump via at least one second valve, and wherein the at least one condenser is in thermal communication, or fluid communication, via the working fluid with the at least one liquid desiccant generator/heat exchanger combination; at least one fluid accumulator designed to receive and utilize the

at least one working fluid, wherein the at least one fluid accumulator is in fluid communication via the at least one working fluid with the at least one condenser via at least one third valve; at least one geothermal heat sink/heat exchanger combination designed to receive and utilize the at least one working fluid, wherein the at least one geothermal heat sink/heat exchanger combination is in thermal communication, or fluid communication, via the at least one working fluid with the at least one condenser, and wherein the at least one geothermal heat sink/heat exchanger combination is in thermal communication, or fluid communication, via the at least one working fluid with the at least one fluid accumulator via at least one third valve; and at least one evaporator designed to receive and utilize the at least one working fluid, wherein the at least one evaporator is in thermal communication, or fluid communication, via the at least one working fluid with the at least one geothermal heat sink/heat exchanger combination via at least one fourth valve, and wherein the at least one evaporator is in fluid communication via the at least one working fluid with the at least one heat pump.

In still another embodiment, the present invention relates to a heat pump system comprising: at least one working fluid; an upper loop comprising: at least one pump; at least one solar collector; at least one turbine; and at least one condenser, wherein the at least one pump, the at least one solar collector, the at least one turbine and the at least one condenser are all designed to receive and utilize the at least one working fluid and are all in fluid communication via the at least one working fluid and together form the upper loop; and a lower loop comprising: at least one heat pump; at least one condenser; at least one evaporator, wherein the at least one heat pump, the at least one condenser and the at least one evaporator are all designed to receive and utilize the at least one working fluid and are all in fluid communication via the at least one working fluid and together form the lower loop, and wherein the bottom loop is in fluid communication with the top loop via at least two valves.

In still another embodiment, the present invention relates to a heat pump system comprising: at least one working fluid; at least two photovoltaic cells; at least one heat pump; at least one absorption chiller; at least one process heat unit; at least one hot water device; at least one condenser; and at least one evaporator, wherein the at least two photovoltaic cells, the at least one heat pump, the at least one absorption chiller, the at least one process heat unit, the at least one hot water device, the at least one condenser and the at least one evaporator are all designed to receive and utilize the at least one working fluid and are all in fluid communication, or thermal communication, via the at least one working fluid, or a combination of the at least one working fluid and at least heat exchanger, and wherein the heat pump system has a by-pass circuit designed to permit the control of the heat pump system when no cooling is needed.

In still another embodiment, the present invention relates to a heat pump system comprising: at least one working fluid; at least one photovoltaic cell; at least one heat pump; at least one hot water device; and at least one condenser, wherein the at least one photovoltaic cell, the at least one heat pump, the at least one hot water device and the at least one condenser are all designed to receive and utilize the at least one working fluid and are all in fluid communication, or thermal communication, via the at least one working fluid, or a combination of the at least one working fluid and at least heat exchanger, and wherein the heat pump system has a by-pass circuit designed to permit the by-pass of the at least one hot water device.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A through 1D are illustrations of various embodiments of an integrated solar collector and heat pump system in accordance with the present invention;

FIG. 2 is an illustration of one embodiment of an integrated solar collector and heat pump having a supplemental fluid accumulator in accordance with the present invention;

FIG. 3 is an illustration of one embodiment of an integrated solar collector and heat pump having multiple thermal sinks in accordance with the present invention;

FIG. 4 is an illustration of one embodiment of an integrated solar collector and heat pump operating as a radiant cooler in accordance with the present invention;

FIG. 5 is an illustration of one embodiment of an integrated solar collector switchable as a thermal source or sink, and heat pump in accordance with the present invention;

FIG. 6 is an illustration of one embodiment of an integrated solar collector and heat pump with an integrated desiccant dehumidifier in accordance with the present invention;

FIG. 7 is an illustration of one embodiment of an integrated solar collector and heat pump with an integrated power generating expander in accordance with the present invention;

FIG. 8 is an illustration of one embodiment of an integrated solar collector and heat pump having multiple thermal sinks and an integrated photovoltaic cell in accordance with the present invention; and

FIG. 9 is an illustration of one embodiment of an integrated solar collector and heat pump configured as a domestic hot water system in accordance with the present invention.

## DETAILED DESCRIPTION OF THE INVENTION

The present invention generally relates to highly integrated solar collector with a heat pump. In all embodiments, the present invention utilizes the same working fluid within the primary solar collector as the heat pump.

As used herein, the term “non-linear”, as used herein, includes any surface of a solar receiver whose surface shape is described by a set of nonlinear equations. As used herein, the term “microchannel”, as used herein, includes channel dimensions of less than 2 millimeter. As used herein, the term “reflector”, as used herein, includes a surface or surface coating that reflects greater than 50% of at least one portion of the incoming light spectrum, which includes the portions of visible, infrared, and ultraviolet.

As used herein, the term “in thermal continuity” or “thermal communication” includes the direct connection between the heat source and the heat sink whether or not a thermal interface material is used. As used herein, the term “multi-pass”, “multi-pass”, or “multiple passes” includes a fluid flow into at least one portion of a heat exchanger and out of at least one other portion of a heat exchanger wherein the at least one portion of the heat exchanger and the at least one other portion of a heat exchanger can either be thermally isolated from each other or in thermal continuity with each other.

As used herein, the term “fluid inlet” or “fluid inlet header” includes the portion of a heat exchanger where the fluid flows into the heat exchanger. As used herein, the term “fluid discharge” includes the portion of a heat exchanger where the fluid exits the heat exchanger. As used herein, the term “boiler” includes a heat exchanger transferring thermal energy into a working fluid wherein the working fluid is comprised of at least 5% vapor phase. As used herein, the term “superheater” includes a heat exchanger transferring thermal energy into a working fluid wherein the heat exchanger is used to convert saturated steam into dry steam.

In one embodiment, the present invention generally relates to a heat pump system having an integral solar collector that utilizes one working fluid in common between the two elements. Here, as well as elsewhere in the specification and claims, individual numerical values and/or individual range limits can be combined to form non-disclosed ranges.

The heat transfer fluid within the embodiments is, in one embodiment, a supercritical fluid as a means to reduce the pressure drop within the heat exchanger. The supercritical fluid includes fluids selected from the group of organic refrigerants (e.g., R134, R245, pentane, butane), gases (e.g., CO<sub>2</sub>, H<sub>2</sub>O, He<sub>2</sub>), or any suitable combination of two or more thereof. In another embodiment, the supercritical fluid is devoid of hydrogen as a means to virtually eliminate hydrogen reduction or hydrogen embrittlement on the heat exchanger coatings or substrate respectively. By devoid of hydrogen, it is meant that the supercritical fluid has less than about 5 weight percent hydrogen (be it either free, or bound, hydrogen, or the combination of both), less than about 2.5 weight percent hydrogen, less than about 1 weight percent hydrogen, less than about 0.5 weight percent hydrogen, less than about 0.1 weight percent hydrogen, or even zero weight percent hydrogen.

In still another embodiment, the supercritical fluid has a disassociation rate less than 0.5 percent at the operating temperature in which the heat exchanger operates. In still yet another embodiment, the heat transfer fluid is a working fluid wherein the combined energy produced (i.e., both thermal, and electrical) displaces the maximum amount of dollar value associated with the displaced energy produced within all of the integrated components including thermodynamic cycle operable within a power generating cycle, vapor compression cycle, heat pump cycle, absorption heat pump cycle, or thermochemical heat pump cycle.

All of the embodiments can be further comprised of a control system operable to regulate the mass flow rate of the working fluid into the solar receiver, with the ability to regulate the mass flow rate independently for each pass by incorporating a fluid tank having variable fluid levels optionally interspersed between at least one pass and the other. One method of control includes a working fluid inventory management system. The control system regulates the mass flow rate through methods known in the art including variable speed pump, variable volume valve, bypass valves, and fluid accumulators. The control system is further comprised of at least one temperature sensor for fluid discharge temperature and at least one temperature sensor for ambient air temperature or condenser discharge temperature.

Exemplary embodiments of the present invention will now be discussed with reference to the attached Figures. Such embodiments are merely exemplary in nature and not to be construed as limiting the scope of the present invention in any manner. The depiction of heat exchangers predominantly as microchannel heat exchangers having linear porting is merely exemplary in nature and can be replaced with any suitably shaped heat exchanger containing microchannels with dimensions or porting greater than defined by microchannel practice. The depiction of solar collectors predominantly as flat panel non-tracking solar absorbers with integral microchannel heat exchangers is merely exemplary in nature and can be replaced with tracking collectors of 1-axis or 2-axis type, vacuum evacuated tubes or panels, switchable configuration between solar absorber or solar radiator mode, low concentration fixed collector, or high concentration tracking collectors.

The depiction of a heat pump as a vapor compressor device is merely exemplary and can such a heat pump could be

replaced with an absorption heat pump. The compressor type can include a positive displacement device, a gerotor, a ramjet, a screw, and a scroll. Furthermore, and importantly, the heat pump can be a turbo pump, a positive displacement pump where the selection of the device to increase the working fluid pressure and operate as a mass flow regulator is determined by the density at the inlet pressure and discharge outlet. In one embodiment, the incoming working fluid has a density greater than about 50 kg per m<sup>3</sup>, or greater than about 100 kg per m<sup>3</sup>, or even greater than about 300 kg per m<sup>3</sup>.

The depiction of valves as standard mass flow regulators is merely exemplary in nature and any such valves can independently be substituted with one or more variable flow devices, expansion valves, turbo-expanders, two-way or three-way valves. The depiction of methods to remove heat from the working fluid as a condenser is merely exemplary in nature as a thermal sink and can be substituted by any device having a temperature lower than the working fluid temperature including absorption heat pump desorber/generator, process boilers, process superheater, and domestic hot water.

The depiction of desiccant dehumidifier as liquid desiccant dehumidifier is merely exemplary and can be substituted with an adsorption solid desiccant dehumidifier and/or high surface area hydrophilic powders. The depiction of geothermal as thermal source can be low depth subsurface, moderate depth geothermal wells, or high depth geothermal sources such as obtained from oil wells. The depiction of expander as turbine is merely exemplary as a method to reduce the pressure of the working fluid enables the generation of mechanical or electrical energy and can be substituted with turbo-expander, positive displacement device, a gerotor or geroller, a ramjet, screw, or scroll device. The depiction of photovoltaic cell as single concentration device can be substituted with a thin film, low concentration device, Fresnel lens, and high concentration devices. With regard to FIGS. 1 through 9, like reference numerals refer to like parts.

Turning to FIGS. 1A through 1D, FIGS. 1A through 1D represent sequential flow diagrams of one embodiment, and various modifications thereto, of a heat pump with integral solar collector in accordance with the present invention. In the embodiments of FIGS. 1A through 1D heat pump solar collector comprises heat pump 10 in fluid communication with a solar collector 20 with a temperature sensor 32 measuring the discharge temperature of the working fluid from heat pump 10. Another temperature sensor 30 measures the discharge temperature of the working fluid as it leaves solar collector 20 and prior to the fluid entering a thermal sink 40 which is in fluid communication with solar collector 20. Another temperature sensor 31 measures the discharge temperature after leaving thermal sink 40. A pressure sensor 50 measures the discharge pressure from heat pump 10, though the actual placement of pressure sensor 50 can be anywhere downstream of heat pump 10 discharge and upstream of a pressure-reducing device including, for example, an expansion valve or turbo expander.

One exemplary method of control is to vary the discharge pressure of heat pump 10 such that the temperature of the working fluid being discharged after the solar collector, which enables the heat pump energy input to be minimized where heat pump 10 concurrently achieves the desired working fluid mass flow requirement and discharge temperature prior to the solar collector. The discharge pressure downstream of heat pump 10 is a function of the solar flux on solar collector 20 as a method of minimizing the operating costs of the heat pump with integral solar collector as the heat pump requires mechanical and/or electrical energy. The heat of compression resulting from heat pump 10 provides a high

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coefficient of performance temperature gain (i.e., lift) that is subsequently increased further by solar collector 20. The control system decreases the pressure gain to ensure that thermal sink 40 both achieves the required heat transfer and discharge temperature such that heat pump 10, when solar collector 20 provides the majority of the heat source into the working fluid, operates predominantly as a mass flow regulator resulting in a reduced operating cost of heat pump 10. Another advantage of this embodiment is the elimination of a heat exchanger to transfer thermal energy captured from solar collector 20 into the working fluid, and also eliminating a secondary heat transfer fluid within solar collector 20. In one embodiment, the working fluid is a fluid that has virtually no (e.g., less than about 1.0 percent, less than about 0.5 percent, and even less than about 0.05 percent) thermal degradation resulting particularly from solar collector stagnation. One exemplary working fluid includes carbon dioxide, with one embodiment employing a heat pump discharge pressure greater than the supercritical pressure of carbon dioxide. Additional working fluids include refrigerants, water, and gases.

In another embodiment, carbon dioxide with a discharge pressure greater than its supercritical pressure is utilized in conjunction with solar collector 20 being a microchannel device to achieve superior heat transfer with low pressure drops. Another important design advantage is the selection of a heat pump 10 that either operates oil free, thus eliminating the potential of hydraulic oil from disassociating (i.e., breaking down) within, or due to, solar collector 20. Alternatively heat pump 10 can utilize an electrostatic collector to collect any lubricant utilized within heat pump 10, with one exemplary being ionic liquids. An ionic liquid has the further advantage of having essentially no vapor pressure in combination of having electrostatic attraction as a method of limiting heat pump 10 lubricant from entering solar collector 20. FIGS. 1A through 1D illustrate four alternative configurations such that "A" is the inlet of the working fluid into heat pump 10, and "B" is the discharge of the working fluid downstream of thermal sink 40. The first configuration, FIG. 1A, depicts an expander 60 downstream of thermal sink 40 as a method of recovering at least a portion of the mechanical/electrical energy expended during in order to obtain the heat pump compression. This configuration would be typical for domestic hot water, air conditioning, refrigeration, industrial processes including processes currently serviced by traditional combustion powered boilers, furnaces, dryers, etc. Expander 60's discharge pressure is regulated by using feedback on the measured pressure by pressure sensor 50 and discharge temperature as measured by temperature sensor 33. It is further anticipated that an external combustor can be downstream of solar collector 20 and upstream of thermal sink 40 as a method to further increase the working fluid temperature. This configuration is especially desired for industrial or power generation processes that involve heating of air (i.e., less dense than working fluid thus requiring significantly larger heat exchangers) as a method of superheating the working fluid to the desired operating temperature of thermal sink 40. In the embodiment where the present invention utilizes the same working fluid for the heat pump as the solar collector in the case of instances where temperatures exceed about 350° C., only certain types of working fluids can be utilized. Suitable working fluids in this instance include, but are not limited to, ammonia, carbon dioxide and water. Water, although an possible choice, is less desirable due to the discontinuous thermophysical properties as water transitions to steam.

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In FIG. 1B another configuration replaces the expander with an expansion valve 90 where the expansion valve as known in the art can operate as a variable controlled device, open/close switch, and modulated to be a pulsing device to enhance heat transfer properties. Expansion valve 90's discharge pressure is regulated using feedback on the measured pressure by pressure sensor 52 and discharge temperature as measured by temperature sensor 34. This configuration, though not as efficient as that of FIG. 1A, has a lower capital cost thus being implemented when the system scale or financial return on investment doesn't justify the additional expense of an energy recovery expander 60. The working fluid downstream of the expansion valve provides cooling through an evaporator 80 thus operating as an air conditioner, chiller, refrigerator, or freezer which is dependent on the discharge temperature as measured by temperature sensor 34.

In FIG. 1C still another configuration is illustrated where a closed loop is utilized, such that the heat pump effectively operates as a mass flow regulator whereby the pressure gain between heat pump 10 inlet is a nominal amount solely to overcome pressure losses associated with the working fluid passing through the entire circulation loop including solar collector 20. In FIG. 1D still another configuration is illustrated where a system further comprises a fluid accumulator 130 and a control valve 95 as a method to buffer the inventory of working fluid within the circulation loop. Fluid accumulator 130 in its simplest form operates as a temporary storage of working fluid when the operating pressure within the circulation loop is within 10 psi of the maximum operating pressure of any individual component. In one embodiment, the present invention incorporates a control system to open and close the one or more valves of the system of FIG. 1D. In still another embodiment, the portion of FIG. 1D composed of fluid accumulator 130 and control valve 95 can be utilized in conjunction with any one of the embodiments of FIGS. 1A through 1C.

Turning to FIG. 2, FIG. 2 is a sequential flow diagram of one embodiment of a heat pump with integral solar collector in accordance with the present invention. In the embodiment of FIG. 2, the system further comprises a fluid accumulator 130 configured predominantly as an emergency working fluid inventory storage vehicle where an open/close valve 90 enables a partial stream of the working fluid, which is now at the higher pressure as measured by pressure sensor 50 having a temperature as measured by temperature sensor 31. The working fluid passes through a condenser 70 in order to increase the density of the working fluid prior to entering fluid accumulator 130. In one embodiment, condenser 70 is located within fluid accumulator 130, thus enabling the condenser (effectively a heat exchanger) to operate as an evaporator/heater. The control system would switch the condenser from cooling to heating mode once the heat pump discharge pressure (i.e., working fluid pressure downstream of the heat pump discharge) drops to an amount lower than the maximum operating pressure minus an anti-cycling threshold. The control system would then subsequently open valve 90 once the working fluid within fluid accumulator 130 exceeds the target set point as measured by temperature sensor 30.

Turning to FIG. 3, FIG. 3 is a sequential flow diagram of one embodiment of a heat pump with integral solar collector in accordance with the present invention. In the embodiment of FIG. 3 heat pump solar collector depicts one scenario having parallel circuits and multiple thermal sinks. Heat pump 10, as noted earlier, can operate as mass flow regulator (i.e., booster pump), more traditional vapor compressor, or more traditional turbo pump. A control system operates the valves as a method of controlling the mass flow within each

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parallel circuit. The top circuit is controlled by valve 90 to enable the working fluid to pass through solar collector 20. The invention contemplates and encompasses solar collector 20 operating either as a solar absorber or solar radiator thus providing the ability to provide “free” heating or cooling respectively by leveraging the high surface area. The working fluid downstream of the solar collector transfers thermal energy via a heat exchanger 80, which can be manufactured using a wide range of materials (e.g., conductive polymers, aluminum, stainless steel, etc.) and designed using methods known in the art (e.g., microchannel, shell and tube, plate, etc.), into thermal sink 41. The working fluid downstream of heat exchanger 82 mixes with working fluid that passes through valve 91, thus effectively operating as a solar collector bypass valve, and sequentially passes through a second thermal sink 40 that has a lower target set point than thermal sink 41. Another thermal sink 42 as illustrated in FIG. 3 removes more thermal energy from the working fluid, though the working fluid temperature will be at a lower temperature than the two aforementioned thermal sinks 41 and 40. Valve 92 enables working fluid to enter fluid accumulator 130. The full working features as noted in FIG. 2 are not repeated visually for the purpose of brevity.

Turning to FIG. 4, FIG. 4 is a sequential flow diagram of one embodiment of a heat pump with integral solar collector in accordance with the present invention. In the embodiment of FIG. 4 heat pump solar collector operates as a radiant cooler. A heat pump 10 increases the operating pressure as measured by the pressure sensor 50 of the working fluid which also has its temperature increased due to heat of compression as measured by temperature sensor 30. A secondary heat transfer fluid, such as domestic hot water is circulated by a pump 72 through a heat exchanger 80 to remove thermal energy of the working fluid through a thermal sink 40. This serves the purpose of providing the first stage of cooling prior to reaching solar collector 20 configured in the radiant cooling mode. The inlet temperature into solar collector 20 is measured by temperature sensor 31 and the discharge temperature is measured by temperature sensor 32. Solar collector 20 when operating as a radiant cooler dissipates black body radiation to the sky and therefore effectively operates as a pre-cooler/sub-cooler to the working fluid prior to reaching expansion valve 91. The now expanded working fluid provides cooling that absorbs thermal energy from a thermal source in thermal communication with evaporator 80. Heat pump 10 inlet pressure and temperature are measured respectively by pressure sensor 51 and temperature sensor 33. An alternate configuration for thermal sink 40 is accomplished using an air condenser that contains one or more condenser fans instead of a secondary heat transfer fluid.

Turning to FIG. 5, FIG. 5 is a sequential flow diagram of one embodiment of a heat pump with integral solar collector in accordance with the present invention. In the embodiment of FIG. 5 heat pump solar collector depicts another configuration for switching solar collector 20 between a thermal sink 40 and thermal source mode. In this configuration, the solar collector is optionally under vacuum while operating in thermal source mode and has ambient air flowing over solar collector 20's surface area. The working fluid then subsequently passes through thermal sink 40. Two two-way valves 111 and 110 are depicted to switch fluid flow direction such that the heat pump can operate in air conditioning or heating mode, known in the art as a reversible heat pump. Heat pump 10 has common evaporator 80 and expansion valve 91 (alternatively expander) and condenser (which is depicted as either thermal sink 40 or solar collector 20).

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Turning to FIG. 6, FIG. 6 is a sequential flow diagram of one embodiment of a heat pump with integral solar collector in accordance with the present invention. In the embodiment of FIG. 6, heat pump 10 and solar collector 20 are depicted as further comprising a liquid desiccant generator 120 and a geothermal 140 as a thermal sink. It is understood that the heat pump with integral solar collector can operate with either the liquid desiccant generator 120 or geothermal 140 heat sink, as well as the shown combination. Heat pump 10 increases the operating pressure of the working fluid in part by utilizing a controllable valve 90 to provide back pressure upstream of solar collector 20 while also serving as a mass flow control (i.e., working fluid pump). Solar collector 20 increases the working fluid temperature of the portion of the working fluid being transported through the collector as determined by the control system and regulated with valve 90. The operation in FIG. 6 depicts heat pump 10 operating as an air conditioning or refrigeration device to provide the sensible cooling while liquid desiccant generator 120 provides latent cooling. The goal is thus to provide cooling therefore a significant portion of the working fluid is desired to bypass, by regulating control valve 91, solar collector 20 while the solar collector boosts the working fluid temperature through heat exchanger 82 as required to regenerate the liquid desiccant solution. The working fluid having been transported through the parallel circuit is combined upstream of condenser 70 where the working fluid temperature approaches the ambient temperature. It is understood that condenser 70 can be selected from the range of known condensers including wet, air, evaporative, etc. FIG. 6 also depicts a working fluid mass management control system though represented for brevity by a control valve 93 to enable working fluid to enter or leave fluid accumulator 130 as noted in earlier embodiments. The working fluid can then be optionally sub-cooled through a heat exchanger 82 in thermal communication with a shallow depth (i.e., surface as known in the geothermal heat pump application, as compared to deep well geothermal for power generation) geothermal 140 that serves as a thermal sink upstream of expansion valve 92. Expansion valve 92 decreases the pressure achieving rapid cooling of the working fluid that subsequently absorbs heat through evaporator 80.

Turning to FIG. 7, FIG. 7 is a sequential flow diagram of one embodiment of a heat pump with integral solar collector in accordance with the present invention. In the embodiment of FIG. 7 heat pump solar collector depicts an integral power generating cycle with an air conditioning/refrigeration thermodynamic cycle where both systems operate on the same working fluid. Beginning the cycle downstream of heat pump 10, heat pump 10 increases the working fluid pressure to the same low side pressure of the power generating cycle (which is downstream of valve 91 and condenser 70). The working fluid downstream of heat pump 10 then passes through condenser 71 to condense the working fluid prior to reaching pump 160 as a method of limiting cavitation. Pump 160 subsequently raises the working fluid, which is now at a significantly higher density, to the power generating high side pressure. The high pressure working fluid, which has increased the working fluid temperature by the heat of compression, now passes through solar collector 20 to vaporize and optionally to superheat the fluid as a means of increasing the enthalpy and thermodynamic efficiency of the power generating cycle. The now superheated working fluid enters turbine 150 inlet in order to produce shaft work (i.e., mechanical energy) that can further be transformed into electricity or hydraulic energy. As known in the art, the working fluid enters condenser 70 in order to reduce the pumping energy requirements to return the relatively cool working fluid to the high

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side pressure. It is understood that the turbine can be any expander device, as the pump can also include a turbo-pump or positive displacement devices. The control system regulates in real time the mass flow of the working fluid that will further be expanded in order to match the air conditioning/ refrigeration demands with thermal energy being transferred through evaporator **80**. It is further understood that pump **160**, heat pump **10**, and turbine **150** can operate at partial loads through means as known in the art.

Turning to FIG. **8**, FIG. **8** is a sequential flow diagram of one embodiment of a heat pump with integral solar collector in accordance with the present invention. In the embodiment of FIG. **8** heat pump solar collector depicts a hybrid solar thermal and photovoltaic configuration. The precise objective of the integrated heat pump and photovoltaic cell system is to operate with the control system pressure and temperature control such that the working fluid transforms from a liquid/ supercritical to a vapor/superheated fluid within the backside of photovoltaic cell **200**. The operating pressure is dynamically modulated such that the temperature at state point #2 is less than or lesser of the maximum junction temperature of PV cell **200** or desired operating temperature. The working fluid subsequently passes through solar collector **220** to ensure that the working fluid doesn't create cavitation in heat pump **10**. The now high pressure working fluid also at the elevated temperature due to heat of compression is at sufficiently high temperatures to drive a range of thermal sinks. These thermal sinks include single, double or triple effect absorption chillers **230**. Subsequently the working fluid passes through thermal sinks requiring sequentially lower operating temperatures such as process heat **240** and then domestic hot water **250**. The control system will enable the working fluid to pass through condenser **70** in the event the working fluid temperature remains higher than the ambient or wet bulb temperature, which would be obtained by activating the condenser fans/ motors. The working fluid now transfers thermal energy by absorbing energy through evaporator **80** and now returning to the backside of the PV cell **200** where thermal energy is transferred into the working fluid through the embedded microchannel heat exchanger **210**.

Turning to FIG. **9**, FIG. **9** is a sequential flow diagram of one embodiment of a heat pump with integral solar collector in accordance with the present invention. In the embodiment of FIG. **9** heat pump solar collector depicts a domestic hot water heat pump utilizing the same working fluid within the entire system. This embodiment anticipates the utilization of traditional working fluids where a maximum temperature limit must be maintained to ensure no thermal disassociation or break down occurs. The method of control includes a dynamic control system that ensures the operating temperature of the working fluid downstream of solar collector **220**, which is, in one embodiment, a microchannel heat exchanger, is less than the maximum working fluid temperature and also to ensure that the working fluid is a vapor prior to entering heat pump **10**. The control system ideally has the means to control the discharge pressure, the mass flow rate, and bypass valves including a variable diverter valve **260** having variable positions to modulate the transferring of heat from the working fluid into the domestic hot water system **250**. The working fluid subsequently enters the condenser **70** where the condenser motors and fans are controlled in order to maximize energy transfer from the solar collector to the domestic hot water as a function of the solar flux, ambient temperature, domestic hot water consumption, and/or domestic hot water storage tank temperature.

It is understood in this invention that a combination of scenarios can be assembled through the use of fluid valves

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and/or switches such that any of the alternate configurations can be in parallel enabling the solar collector to support a wide range of thermal sinks.

Although the invention has been described in detail with particular reference to certain embodiments detailed herein, other embodiments can achieve the same results. Variations and modifications of the present invention will be obvious to those skilled in the art and the present invention is intended to cover in the appended claims all such modifications and equivalents.

What is claimed is:

**1.** A heat pump system comprising:

- at least one working fluid;
- at least one heat pump having an inlet and an outlet designed to receive and utilize the at least one working fluid;
- at least one solar collector having an inlet and an outlet designed to receive and utilize the at least one working fluid, wherein the inlet of the at least one solar collector is in fluid communication via the at least one working fluid with the outlet of the at least one heat pump;
- at least one working fluid inventory storage system in fluid communication with both the at least one heat pump and the at least one solar collector, wherein the at least one working fluid inventory storage system is designed to work in a bi-directional manner, and wherein the at least one working fluid inventory storage system comprises:
  - at least one bi-directional expansion valve in fluid communication with both the outlet of the at least one heat pump and the inlet of the at least one solar collector via the at least one working fluid;
  - at least one bi-directional condenser in fluid communication with the at least one bi-directional expansion valve via the at least one working fluid; and
  - at least one bi-directional fluid accumulator in fluid communication with the at least one bi-directional condenser via the at least one working fluid;
- a first temperature sensor in fluid communication with the at least one working fluid, the first temperature sensor disposed downstream from the at least one heat pump and upstream of the at least one solar collector;
- a second temperature sensor in fluid communication with the at least one working fluid, the second temperature sensor located downstream of the at least one solar collector;
- a third temperature sensor in fluid communication with the at least one working fluid, the third temperature sensor disposed between the at least one bi-directional expansion valve and the at least one bi-directional fluid accumulator; and
- a first pressure sensor in fluid communication with the at least one working fluid, the first pressure sensor disposed between the at least one bi-directional expansion valve and the at least one bi-directional fluid condenser.

**2.** A heat pump system comprising:

- at least one working fluid;
- at least one heat pump designed to receive and utilize the at least one working fluid;
- at least one thermal sink designed to receive and utilize the at least one working fluid, wherein the at least one thermal sink is in fluid communication via the at least one working fluid with the at least one heat pump via a first two-way valve, and wherein the first two-way valve is disposed downstream from the at least one heat pump;
- at least one solar collector designed to receive and utilize the at least one working fluid, wherein the at least one solar collector is in fluid communication via the at least

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one working fluid with the at least one thermal sink, and wherein the at least one solar collection is in fluid communication via the at least one working fluid with the at least one heat pump via the first two-way valve; and  
 at least one evaporator designed to receive and utilize the at least one working fluid, wherein the at least one evaporator is in fluid communication via the at least one working fluid with both the at least one thermal sink and the at least one solar collector via a second two-way valve and at least one valve, wherein:  
 the second two-way valve and the at least one valve are disposed between the at least one evaporator and the at least one thermal sink,  
 the second two-way valve and the at least one valve are further disposed between the at least one evaporator and the at least one solar collector, and  
 the at least one evaporator is in fluid communication via the at least one working fluid with the at least one heat pump.  
 3. A heat pump system comprising:  
 at least one working fluid;  
 at least one heat pump designed to receive and utilize the at least one working fluid;  
 at least one solar collector designed to receive and utilize the at least one working fluid, wherein the at least one solar collector is in fluid communication via the at least one working fluid with the at least one heat pump;  
 a first valve disposed downstream from the at least one heat pump and upstream of the at least one solar collector;  
 at least one liquid desiccant generator/heat exchanger combination designed to receive and utilize the at least one working fluid, wherein the at least one liquid desiccant generator/heat exchanger combination is in thermal communication, or fluid communication, via the working fluid with the at least one solar collector;  
 at least one condenser designed to receive and utilize the at least one working fluid, wherein the at least one condenser is in fluid communication via the at least one working fluid with the at least one heat pump, and wherein the at least one condenser is in thermal communication, or fluid communication, via the working fluid with the at least one liquid desiccant generator/heat exchanger combination;  
 a second valve disposed between the at least one condenser and the at least one heat pump;  
 at least one fluid accumulator designed to receive and utilize the at least one working fluid, wherein the at least one fluid accumulator is in fluid communication via the at least one working fluid with the at least one condenser;  
 a third valve disposed between the at least one fluid accumulator and the at least one condenser;  
 at least one geothermal heat sink/heat exchanger combination designed to receive and utilize the at least one working fluid, wherein the at least one geothermal heat sink/heat exchanger combination is in thermal communication, or fluid communication, via the at least one working fluid with the at least one condenser, and wherein the at least one geothermal heat sink/heat exchanger combination is in thermal communication, or

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fluid communication, with the at least one fluid accumulator via the at least one working fluid, and wherein the third valve is disposed between the at least one fluid accumulator and the at least one geothermal heat sink/heat exchanger; and  
 at least one evaporator designed to receive and utilize the at least one working fluid, wherein the at least one evaporator is in thermal communication, or fluid communication, via the at least one working fluid with the at least one geothermal heat sink/heat exchanger combination via a fourth valve, and wherein the at least one evaporator is in fluid communication via the at least one working fluid with the at least one heat pump.  
 4. A heat pump system comprising:  
 at least one working fluid;  
 an upper loop comprising:  
 at least one pump;  
 at least one solar collector;  
 at least one turbine; and  
 at least one condenser,  
 wherein the at least one pump, the at least one solar collector, the at least one turbine and the at least one condenser are all designed to receive and utilize the at least one working fluid and are all in fluid communication via the at least one working fluid and together form the upper loop; and  
 a lower loop comprising:  
 at least one heat pump;  
 at least one condenser;  
 at least one evaporator,  
 wherein the at least one heat pump, the at least one condenser and the at least one evaporator are all designed to receive and utilize the at least one working fluid and are all in fluid communication via the at least one working fluid and together form the lower loop, and  
 wherein the bottom loop is in fluid communication with the top loop via at least two valves.  
 5. A heat pump system comprising:  
 at least one working fluid;  
 an evaporator configured to receive the at least one working fluid;  
 at least one photovoltaic cell disposed downstream from the evaporator and in thermal communication with the evaporator via a heat exchanger;  
 at least one heat pump disposed downstream from the at least one photovoltaic cell;  
 at least one hot water device disposed downstream from the at least one heat pump;  
 at least one condenser disposed downstream from the at least one hot water device;  
 a first valve disposed downstream from the at least one condenser and upstream of the evaporator; and  
 a by-pass circuit designed to permit the at least one working fluid to by-pass of the at least one hot water device.  
 6. The heat pump system of claim 5, wherein the at least one photovoltaic cells comprises at least two photovoltaic cells.

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